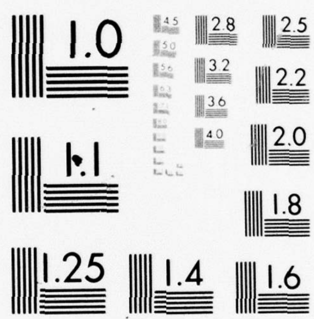
AD-A048 220 PRC INFORMATION SCIENCES CO ROME N Y F/G 8/2
CARTOGRAPHIC COMPILATION STUDY. VOLUME I. SYSTEM REQUIREMENTS A--ETC(U)
OCT 77 M L TAYLOR, R P O'CONNOR F30602-73-C-0036
UNCLASSIFIED RADC-TR-77-340-VOL-1 NL

1 of 4
ADA048 220



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

RADC-TR-77-340, Volume I (of two)
Final Technical Report
October 1977

CARTOGRAPHIC COMPILATION STUDY
System Requirements and Design Analyses

PRC Information Sciences Company

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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APPROVED: Joseph J. Palermo
JOSEPH J. PALERMO
Project Engineer

APPROVED: Howard Davis
HOWARD DAVIS
Technical Director
Intelligence and Reconnaissance Division

FOR THE COMMANDER: John P. Huss
JOHN P. HUSS
Acting Chief, Plans Office

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
RADC-TR-77-340, Vol-1 (of two)

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

4. TITLE (and Subtitle)
CARTOGRAPHIC COMPILATION STUDY. Volume I.
System Requirements and Design Analyses.

5. TYPE OF REPORT & PERIOD COVERED
Final Technical Report.
April 1974 - July 1977.

6. PERFORMING ORG. REPORT NUMBER
N/A

7. AUTHOR(s)
Mr. M. L. Taylor
[redacted] R. P. O'Connor

8. CONTRACT OR GRANT NUMBER(s)
F30602-73-C-0036

9. PERFORMING ORGANIZATION NAME AND ADDRESS
PRC Information Sciences Company
8606 Turin Road
Rome NY 13440

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
J.O. 43030301
64701B

11. CONTROLLING OFFICE NAME AND ADDRESS
Rome Air Development Center (IRRP)
Griffiss AFB NY 13441

12. REPORT DATE
October 1977

13. NUMBER OF PAGES
297

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Same

296p.

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer: Joseph J. Palermo (IRRP)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cartography
Compilation
Computers
Interactive

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report contains an analysis of the digital cartographic compilation process with attendant hardware and software requirements. A review of available off-the-shelf hardware is included with a trade-off analysis of available hardware vs required hardware. A selection of the best hardware configuration is made and a throughput analysis is performed comparing the configured system to the current manual process.

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PREFACE

This final technical report was prepared by PRC Information Sciences Co., 7600 Old Springhouse Road, McLean, Virginia. The report covers work performed under contract F30602-73-C-0036 for Rome Air Development Center, GAFB, New York. Mr. Joseph Palermo was the RADC Project Engineer.

PRC/ISC would like to thank the following Government personnel for their technical support and direction during the course of the effort.

<u>RADC</u>

Maj. James Broglie
Joseph Palermo

<u>DMA</u>

Robert Penny
Fred Hufnagel
Gene Knight
Frank Mirkay
Elio Barbis
Terrance Halinan

We would also like to state our appreciation for the technical support and interest of personnel from Singer Librascope Division, Glendale, CA and Laser-Scan Ltd., Cambridge, England.

TR MAJOR SECTIONS

VOLUME I

SYSTEM REQUIREMENTS & DESIGN ANALYSES

VOLUME II

DESIGN SPECIFICATIONS - ADVANCED REVISION & COMPILATION SYSTEM

VOLUME I

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EVALUATION

This final technical report under Item B00A of the subject contract advances the RADC knowledge in the area of digital compilation/revision processing. This is a significant step toward the development, for the Defense Mapping Agency, of a data revision system, both analog and digital, in support of current and planned DOD weapon systems. The information contained in the report will form the basis for, joint RADC/DMA, development of final system function specifications and subsequent procurement.

Joseph J Palermo

JOSEPH J. PALERMO
Project Engineer

I. INTRODUCTION

A. Purpose and Scope

The purpose of this technical report is to present the results of the systems analysis and design specification work for an advanced cartographic compilation and revision system. The report is intended to convey the salient findings for each task undertaken during the course of the effort and present the design concept and functional design specifications for the advanced compilation system. The report is divided into two volumes:

Volume I - System Requirements and Design Analyses
Volume II - System Design Specifications

Volume I contains the following: a summary of the project and technical findings; analysis of the compilation function; definition of system requirements and design concepts; technology assessments and alternative configurations; and projected system throughput and benefits. Volume II contains the design specification for the "Advanced Revision & Compilation System" (ARCS). The design includes a definition of system functions, hardware requirements and design strategies, operational scenario, and software organization and processing requirements.

B. <u>Technical Approach</u>

The technical approach for performing the effort consisted of two major product phases:

Phase I - Study and Analysis
Phase II - Design Analysis and Specification

<u>PHASE I - STUDY AND ANALYSIS</u>

The objective of Phase I was to define the functional and operational requirements of the compilation processes in an advanced cartographic system environment. Phase I consisted of four sub-tasks: Sub-Task 1.1--Planning and Data Collection; Sub-Task 1.2--Study of Compilation Processes and Requirements; Sub-Task 1.3--Evaluation of Experimental Systems; and Sub-Task 1.4--Analysis and Definition of Compilation Processes in an Advanced Environment.

SUB-TASK 1.1 - PLANNING AND DATA COLLECTION - This sub-task consisted of performing all task planning and scheduling activities, PRC/RADC coordination meetings, and collection with preliminary review of pertinent reference materials. Interviews were conducted at RADC with RADC and on-site DMA representatives.

SUB-TASK 1.2 - STUDY OF COMPILATION PROCESSES AND REQUIREMENTS - This sub-task consisted of an in-depth review and definition of current and projected cartographic compilation processes. A trip to DMAAC was conducted for data collection and discussion of compilation practices. Items defined by this sub-task included the following:

- cartographic production flow
- compilation processes
- sources of information
- products, current and future (formats, scales, contents, volume, etc.)
- production standards
- system interfaces

SUB-TASK 1.3 - EVALUATION OF EXPERIMENTAL COMPILATION SYSTEMS - The objective of this sub-task was to collect all pertinent data via documentation review, personal interviews and examination of experimental compilation devices and systems. Activities performed included: identification of experimental systems providing compilation type functions; collection and review of system and capability descriptions; examination and demonstration testing of the most pertinent systems, and evaluation of techniques and capabilities which are applicable to the compilation system definition.

SUB-TASK 1.4 - DEFINITION OF COMPILATION PROCESSES IN AN AUTOMATED ENVIRONMENT - This sub-task represented a culmination of sub-tasks 1.2 and 1.3, resulting in definition of the requirements of the compilation process in an automated cartographic environment. The requirements were defined in terms of the following:

- o sources and formats of information
- o products to be generated
- o product profiles
- o manual and automated functions to be performed
- o interfaces
- o product generation time frames
- o operational concepts and characteristics

This sub-task primarily consisted of interpretation and extrapolation of the current compilation process into requirements for the automated system.

PHASE II - DESIGN AND SPECIFICATION

The objectives of Phase II were to translate the concepts and requirements, defined in Phase I into a set of alternative design concepts and configurations; and develop a detailed system design specifications for the most effective design concept. Phase II consisted of three sub-tasks: Sub-Task 2.1--Alternate Designs and Trade-Off Study; Sub-Task 2.2--System Design; and Sub-Task 2.3--System Specification.

SUB-TASK 2.1 - ALTERNATIVE DESIGNS AND TRADE-OFF STUDY - This sub-task consisted of analysis and extrapolation, where necessary, of the design requirements into a set of detailed design parameters. The task team conceived and explicitly defined a number of design alternatives considering state-of-the-art in applicable areas, development timeframe, technical risks, cost, etc. Each alternative design was described along common topics. This was followed by an extensive trade-off analysis. A working paper (or memorandums), describing the alternative designs and evaluations, were prepared and submitted to the Government. Extensive coordination was conducted between the task team and the Government to discuss the alternatives and to resolve which design to pursue.

SUB-TASK 2.2 - SYSTEM DESIGN - This sub-task was directed specifically at design definition of the selected system configuration. Specific items addressed included: design overview; functional processes; hardware/software/manual processes; and hardware/software configuration.

SUB-TASK 2.3 - SYSTEM SPECIFICATION - This sub-task developed detailed specifications of the designed system. Detailed specifications were defined for all hardware, software and system processes.

REPORTING

The project team conducted numerous technical exchanges with the RADC Project Engineer and other designated DMA personnel. In addition to monthly status reports, the following project working papers were produced and delivered to the Government for review and coordination.

1. Compilation Processes
2. Review of Experimental Compilation Systems
3. Compilation System Concept and Requirements
4. Alternative Configuration Analysis
5. Expanded Compilation Analysis
   Task 1 - Source Assessment & Data Extraction Analysis
6. Expanded Compilation Analysis
   Task 2 - Compilation Proofing Analysis

7. Advanced Revision & Compilation System Level 1 - Functional Design Specification
8. Alternative Configurations Augmented with Source Assessment/ Data Extraction
9. Advanced Revision & Compilation System-Interactive Subsystem Operational Scenario of Major Functions
10. Source Assessment/Data Extraction Design Concept Update
11. Advanced Revision & Compilation System-Timing & Memory Analysis
12. Advanced Revision & Compilation System - Comparative Production Throughput Analysis

C. Technical Summary

The effort resulted in development of a system concept, functional requirements, and operational strategy for performing computer assisted cartographic compilation and revision. Design guidelines to employ "off-the-shelf" technology for configuration of an advanced compilation system resulted in extensive trade-off analysis. Two areas are of particular importance. Current graphic display devices are not perfectly suited to the demanding requirements of graphic compilation/revision. Combinations of selected graphic display techniques (i.e., refresh CRT and laser plot and large screen projection) can be employed to achieve a sufficient level of display capabilities. Advances in liquid crystal displays were recently revealed which, if pursued, may offer near optimal solutions to cartographic display requirements. The second area is associated with a projection device to support assessment of graphic sources and digital data, and subsequent data extraction from the graphic sources. This type of device will require hardware design and integration of optical projection and digitizing components.

A production throughput model was developed for three possible configurations for the advanced system. The selected configuration represented a 20% to 37% improvement in resource utilization over the other configurations. The throughput model projects a possible improvement, over current manual compilation/revision processes, of approximately 50% in man-hours and calendar days.

The system recommended for prototype development consists of a batch processing subsystem and interactive subsystem. The batch subsystem provides the requisite set of processes to commonize and format digital feature data for input to the interactive subsystem. The basic batch software processes are well established in the cartographic community.

The interactive subsystem represents the most challenging area for development and potentially one of the most technically impacting and rewarding in advanced cartography. This subsystem will provide the cartographer with a wide range of interactive processing capabilities to comply with the following major functional areas:

- o Graphic Display and Interactive Support
- o Source Assessment
- o Feature Data Extraction
- o Interactive Generalization
- o Feature Manipulation
- o Alphanumeric Text Assignment
- o Graphic Proofing

The interactive subsystem configuration recommended for the prototype development consists of three work station types: Source Assessment Station, Interactive Compilation Station, and Proofing Analysis Station. The work stations will be serviced by a master processor for common input/output, data base, and general utility services.

II. REQUIREMENTS ANALYSIS

A. Introduction

The purpose of this section is to describe the analysis of current DMAAC chart production phases and those compilation processes being considered for computer applications. Design of an automated compilation system will replace many of the current processes and must interface with certain production steps and procedures. Therefore, a thorough understanding of compilation processes, procedures, and requirements is deemed necessary for effective and comprehensive design of a computer based compilation system. Much of this section discusses general aspects of chart production and compilation processes. One of the major goals is to identify and describe those particular compilation processes which are especially relevant to automation of the compilation phase.

B. Cartographic Production Overview

1. Product Types and Schedules

Defense Mapping Agency Aerospace Center provides a wide range of cartographic products and services to users. The types of products generally applicable to the compilation study fall within one of four categories:

- o navigation and planning charting products
- o air target material products
- o joint operations and planning graphics
- o special products (graphic and digital)

a. Navigation and Planning (NAVPLAN) and Air Target Material (ATM) Charts

The purpose of the NAVPLAN Program is to produce charts which can be used for planning and execution of flights at various altitudes and speeds. The series of charts included in this category are: TPC, ONC, and JNC. The ATM Program produces materials for planning, execution, and training for bombing operations. Included in the ATM Program are ATC-200, UAM-25, and JOG-R charts. A brief description of products, including scale, format size, projection, feature density, purpose, and production schedules is presented in Appendix A.

b. Joint Operations and Planning Graphics

The Series 1501 (Ground) graphic (JOG-G) is the topographic map version of a coordinated world-wide series at 1:250,000 scale required to support international and joint service air/ground requirements for tactical operations, preflight and operational planning and intelligence briefings.

c. Special Products

Special products produced by DMAAC, considered applicable to an automated compilation station are limited to:

- o Advanced Weapon System Support; DRLMS - (Terrain and Planimetry)

- o Digital Data for development of navigation/guidance display
- o Sensor Simulation Development

These products differ from conventional charting efforts. They are not a coordinated series. The final DMAAC products are either digital representations of cartographic/sensor related features or graphic displays prepared from digital data. The basic input materials used in the preparation of these products are similar in nature and scope to those used in mapping and charting, i.e., evaluated source maps, photographs, and textual reports, and require analysis for applicability, compatibility and utility.

The production of terrain and planimetry related digital products include the TERCOM, MINIBLOCK, and DRLMS programs. These are three of the programs for which terrain and planimetry data are being obtained in digital form. Requirements for this type of data are expected to greatly increase.

2. Production Phases

The phases of cartographic production are generally the same for each chart series. Chart production is divided into the following phases:

- o Research - collection, maintenance and evaluation of cartographic source materials.
- o Compilation - selection of source materials and compilation of all cartographic feature information pertinent to the product purpose and requirements.
- o Color separation - final symbolization and drafting (engraving) of finished color separation negatives.
- o Printing and Distribution - final chart printing and dissemination to users.

A general flow of events for chart production is presented in Figure II-1 .

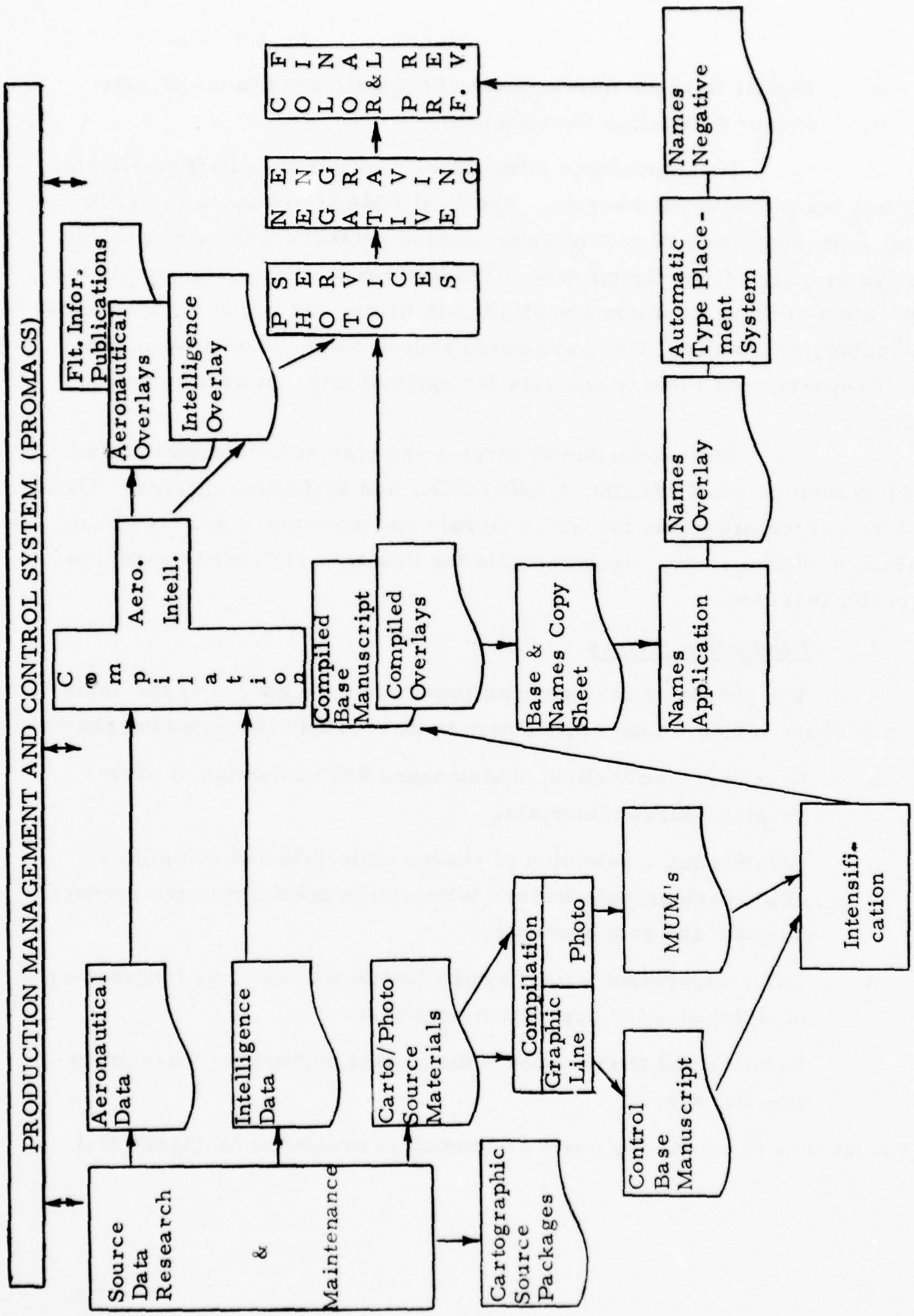


Figure II-1 Production Flow Overview

3. DMAAC Automated Production Systems

DMAAC has been automating its procedures as technical developments have provided improved methods. At the present time, eight automated or computer assisted systems are included in the chart production procedures. These systems are:

- o Cartographic Data Handling System (CDHS)
- o Automatic Type Placement System (ATPS)
- o Analytical Stereoplotters
- o Production Management and Control Systems (PROMACS)
- o Lineal Input System (LIS)
- o CALMA
- o Gerber Plotter
- o Cartographic Data Base

The following sections discuss each of these systems and their functional roles with respect to the compilation effort.

a. Cartographic Data Handling System

The Research Department (RD) has established an automated system, the Cartographic Data Handling System (CDHS), to catalog and provide immediate data on the availability of source data within the cartographic data base. The CDHS maintains five index files of cartographic source data.

- o Automated Map Information File
- o Collateral Automated Intelligence File
- o SAO Automated Intelligence File
- o Tactical Illustration Index File
- o Target Intelligence File

Indexes to all source material and updates to specific areas are kept in Cartographic Information Folio's (CIF) by the Senior Area Specialist (SAS). The CIF contains the most currently updated data. These files include data on the quality of the source, control points and hazards, etc., for use by the compiler. The folio includes a chart of the area with overlays:

1) indicating new feature updates, and 2) indicating more detailed sources and their accuracy.

b. Automatic Type Placement System

The Automatic Type Placement System (ATPS) is a system used to support various type and plotting requirements including the basic names overlays for chart production. The ATPS is comprised of a Computer/Director, composition keyboards, drum type/symbol placement programmers, automated typographic units (Photon 560), and a photocoordinatograph.

c. Analytical Stereoplotters

The Analytical Stereoplotter Systems (AS-11A, B and B1) are used to produce basic manuscripts, digital terrain matrix and contour data, and planimetric data from aerial photography. DMAAC is presently upgrading AS-11 units to provide them with the ability to record digital data on magnetic tape. This data is an important part of the Cartographic Data Base.

There are three programs being pursued in addition to the AS-11 normal charting tasks, TERCOM, MINIBLOCK, and DRLMS. The TERCOM program is primarily involved with the generation of terrain matrices for use in terrain comparison for navigational aids. The MINIBLOCK program is a program to pinpoint the location and elevation of the highest elevation within each block of a grid logically superimposed upon a model of a given area. A considerable amount of effort is being expended in this latter effort scheduled for completion in FY-77. DRLMS data, produced by AS-11B1, is primarily terrain matrices in digital form collected automatically by profiling in a matrix recording mode. The amount of storage required will be significant since the matrices being used and generated are exceedingly dense.

The utilization of the AS-11 digital data with the LIS and CALMA produced data in the unified integrated cartographic data base will require a careful analysis of the user requirements for digital data and data base content, and format. To produce high quality cartographic and

AWS products, the compilation system must be capable of accessing source data regardless of data format or type of output/product.

d. PROMACS

The Production Management and Control System (PROMACS) is a management information system used to support DMAAC cartographic planning and production. PROMACS provides control data to the production management in support of scheduling and monitoring the progress of a cartographic product during its compilation. PROMACS also produces schedules based on product requirements which allow the production management to predict upcoming requirements relative to other product work loads. PROMACS performs computer resource management by predicting requirements for specific runs such as data base queries and plots.

PROMACS integrates the various functional aspects of all DMAAC production. As such, the production schedules produced by PROMACS will be affected by any new production innovations such as the LIS or the Compilation Station. The specific effects of such changes can only be determined once new systems are defined in the production environment.

e. Lineal Input System

The Lineal Input System provides a computerized digitizing process using minicomputers, peripheral tape drives, printers, plotters, line digitizers, and display devices coupled with computer software programs and close cartographer/machine interaction.

The primary function of the LIS is to digitize and maintain digital representations of lineal features and to enable unique identification of each feature through an associated descriptor field keyed to a cartographic data base classification hierarchy. Digitized features can be expressed in a form independent of any specific product or format. The features are intended as input for a digital Cartographic Data Base Processing Subsystem in which specific exploitation-dependent formats may be derived.

The LIS provides a capability for editing cartographic data bases and maintaining the currency of the data base contents. The system produces highly accurate graphic plots, registered in any one of several scales and projection coordinate frames, and provides detailed descriptions of selected features stored within the data bank.

The LIS output is a collection of geographically-related lineal features (a data file) specified as to coordinate area boundaries and feature classes. The LIS may section any file to specified coordinate areas and is able to create files over larger areas by paneling (butt-joining) files covering sections of the required area. Standard LIS output is the data cell -- keyed to the World Aeronautical Chart/World Aeronautical Grid (WAC/WAG geographic segmentation scheme -- and consisting of a WAG Cell measuring 12 minutes in latitude by a variable (approximately 15 minute) longitudinal span.

Primary use of the LIS system at DMAAC has been for the digitization of contour data. This contour data is being used to generate terrain matrices for special weapons systems support. However, it is anticipated that the LIS system will become one of the major digitizing systems which will be used to generate a digital cartographic data base.

The LIS data base contains a more detailed breakdown for feature identification than either the CALMA or AS-11B input systems. The lack of standardization between the existing systems' classification hierarchies may cause the automated extraction process to be limited unless data base standardization is established.

f. CALMA

The CALMA digitizing system is an input system which is presently used to support the Digital Radar Land Mass Study (DRLMS), geographic point positioning, and miscellaneous special products. This system will ultimately be used to generate digital input for the cartographic data base.

The CALMA digitizing system has been upgraded by the addition of Systems, Science, and Software (S^3) edit station. This station will provide the capability to view the CALMA generated digital data and make modifications to the digital data base. The S^3 system is being modified to provide a full edit capability in order to maintain the CALMA produced cartographic data base.

g. Gerber Precision Line/Symbol Plotter

The major function of the Gerber Plotter, with its Honeywell minicomputer controller, is to provide precision plotting of cartographic information. On a prototype basis, edited, symbolized line-centered cartographic data is now being generated by the linear digitizing systems, processed on the 1108, and output for automatic plotting. Primarily now, this plotter is being used to plot precise grids and cartographic projections. The primary plot method is a computer controlled photo light head, exposing lines and flashing symbols directly on photographic film. During FY-76, the CBS Finishing Plotter was phased into color separation production.

h. Cartographic Data Base

There is now an Interim Cartographic Data Base. The Interim Cartographic Data Base includes the data files and index to the DMAAC digital data, as well as any known digital data residing elsewhere; e.g., DMATC. This data base includes magnetic tapes of digital, contour, elevation matrix, and planimetric features data produced by the LIS, CALMA, AS-11B1, as well as other digital files. The generation of the data base library control mechanism represents a first step by DMAAC at control of digital cartographic feature data, as a data base. The follow-on evolution of the CDB into an integrated earth-wide cartographic data base is now in work at DMAAC. This CDB will provide the bulk of the cartographic features in digital form to the compilation system.

C. Descriptions of Conventional Compilation Processes

1. Objectives and Requirements

The compilation function is performed for the purpose of producing a cartographic product which complies with a set of user specifications. The compilation function generally includes a variety of processes performed by a number of personnel ranging from photo copying to feature selection and portrayal. To maintain accuracies and continuity, a set of specifications are maintained for each product, in addition to, a set of procedural standards and tolerances. Procedural standards which are levied on current compilation processes and must certainly be maintained in the automated environment are presented in Appendix B. Standards which are most applicable to automation of compilation processes are:

- o distortion due to generalization shall not exceed .02"
- o positional accuracy of alignment of source shall be within .02"

2. Process Descriptions

The following discussion is a description of the processes involved in the production of charts at DMAAC. The major production areas described are the research for source materials and graphic compilation processes. Photogrammetric compilation processes, while generally providing the most accurate and detailed source materials/data for subsequent product compilations, is not presented below because stereo-compilation is currently viewed as a separate subsystem in an advanced cartographic system environment.

a. Preparation of Compilation Recommendations/Plans

(1) Preliminary Research

The initial step in the preparation of a compilation recommendation or plan is the searching for pertinent source material for a given geographic area. This search, conducted by a researcher, consists of running queries against CDHS and reviewing the Cartographic Information Folio which is a part of the Maintenance of Knowledge Program

at DMAAC. This folio is utilized by research personnel as a basic reference document to source materials. Each folio contains six basic indexes or overlays:

- o Selected Horizontal and Vertical Control Source
- o Horizontal Accuracy of Selected Source
- o Vertical Accuracy of Selected Source
- o Alternate Source
- o Supplementary Source
- o Geographic/Grid Coordinate Corrections

The review of CDHS Listings/Coverage Plots and Folio provides the research/compiler with a list of best source material available for compilation of the various manuscripts.

(2) Source Evaluation

One of the most important processes prior to the preparation of compilation recommendations is source material evaluation. Cartographic source material is evaluated for currency, and horizontal and vertical accuracy. If source maps have not been scaled previously, they will be scaled against geodetic control to determine the positional evaluation (PE). A source material evaluation sheet containing the PE of the source maps is completed.

The results of the evaluations are very important. If the overall positional accuracy of a chart to be compiled does not fall within the specified accuracy requirements, it must be decided whether to continue or terminate the assignment. A chart may be compiled using the best available source, or production may be held up pending the acquisition of more accurate source materials.

Once positional accuracy has been established, the researcher then determines the best source material for compilation of the various physical and cultural features. The most important part of the plan is identification of source to be used for control.

When possible, the source used for control is also used for selection of the major base detail and hypsometric information. Base detail includes the contours, spot elevations, etc. Supplementary sources will be recommended for additional base and hypsometric detail, boundaries, vegetation, and other miscellaneous features. Various intelligence documents and source maps are recommended for selection of significant or checkpoint features. An analysis of source materials, including road maps, technical journals, city maps, etc., is conducted to determine the proper classification of roads, railroads, and populated areas.

(3) Preparation of Compilation Plan

A compilation plan is usually written along with the analysis and evaluation of source materials. Listed are source materials to be used for compilation of the various cultural and physical features. The best method for the holding of control will be noted, along with any anticipated compilation problems which might be encountered. The remainder of the compilation plan indicates the best sources for the selection and portrayal of various physical and cultural features. The plan is then reviewed and approved by the appropriate production and management personnel.

b. Projection and Grid Preparation

(1) Inputs

Chart Master Projection File
USAF Projection Tables
Grid Computations

(2) Process

Upon receipt of a production assignment, the Compilation Section contacts the Negative Preparation Section to determine the availability of the particular chart projection. If the projection master is available, it is sent to Photo Services for copies. If the particular projection is not available, it is constructed with the use of projection tables. The graticule intersection points usually are automatically plotted. It is determined what grids should be shown on the chart. The grid placement

computations are computed on the IBM 1620 computer and sent to the Compilation Section. Information provided includes required grids, zone, spheroid, designator letters, grid box, and corner grid intersections. The grid is plotted automatically on the ATPS Plotter or Aero Service Plotter.

c. Preparation of Selection Overlays

(1) Inputs

Selected Source Maps

(2) Process

If source maps contain a high density of detail such that clutter would result after scale reduction, a selection overlay is prepared by the cartographer. The selection overlay will contain additional feature detail over that which is anticipated to be on the final manuscript, thus allowing the compiler to make final judgements once all information is compiled to a common format (e.g., scale). A selection overlay is compiled by keying a mylar sheet to the selected source map and delineating selected features. The features are usually color coded for ease of recognition.

Preparation of selection overlays is one of the key compilation processes. The compiler makes major cartographic decisions and performs specialized actions which include:

- selection of features, based on product specifications, which he believes should be retained for compilation of the control base manuscript;
- line generalization in concert with detail on the original source and compilation scale;
- alignment shifts because of anticipated congestion after scale reduction; and
- interpreation of content and feature importance on the source.

d. Preparation of Source Materials

(1) Inputs

Selected Source Maps
Selected Overlays
Projection Manuscript

(2) Process

The source maps and selection overlays are reduced to the scale of the chart being compiled so that a common scale and true density portrayal is obtained. A measurement is made between identical graticule intersections on the source and the projection manuscript. A ratio is established and a percentage reduction factor is assigned to each of the source materials. Source to be reduced is sent to Photo Service for reduction by calibrated cameras. Reduced source maps are returned to the compilation section and checked for proper reduction.

e. Panel Control Base

(1) Inputs

Reduced Source Selected for Control and Base Detail
Projection Manuscript

(2) Process

The compiler first obtains all of the reduced source materials which are to be used for compilation of the control base manuscript. The reduced source materials are positioned on the projection manuscript by lining the graticule lines and intersections. If the graticules do not line up properly, a paneling process is required. This involves cutting and spreading of the source maps. Cuts are evenly distributed and the spreads are limited to less than .01 inch. After proper positioning, the source map copies and selection overlays are glued to the projection manuscript.

f. Panel Contour Mosaic

(1) Inputs

Source Maps to be used for Contours
Projection Manuscripts

(2) Process

If the source maps used by the control base are not the same as those to be used for the contour delineation, a contour mosaic is normally compiled. The compiler obtains reduced source maps to be used for contours, and checks for proper reduction. Reduced maps are positioned, paneled, cemented, etc., to the projection copy in the same manner as for the control base.

g. Compile Base Manuscript

(1) Inputs

Control Base Manuscript
Projection Manuscript
Supplementary Source

(2) Process

The base manuscript is compiled from the control base with revisions, as necessary, from supplementary source materials.

Compilation of a chart from larger scale source materials requires major actions to be performed by the compiler. The compiler must be cognizant of the applicable product specifications, tolerance budgets which govern the compilation processes, and appreciate the geographical characteristics of the chart area.

Product specifications provides requirements and guidelines which the compiler follows during feature selection and portrayal processes. While specific directions are provided concerning what major features to include on the product, the cartographer's expertise is exercised for selection of "less than major" features (although certainly important for proper representation of an area) and portrayal of features, particularly

in conflict areas. Sample specifications which requires judgements by the compiler includes the following from JOG-A Product Specifications:

- o <u>Drainage</u>

  No attempt should be made to show all features which are too numerous or too small to show to scale, instead a representative pattern of symbols shall be used.

  Stream measuring .020 inch or more in overall width shall be shown as double-line streams.

  Artificial bodies of water will be shown only when large enough to show without exaggeration of scale.

- o <u>Vegetation</u>

  Perennial vegetation shall be shown when equivalent to or exceeds .10 inch by .10 inch.

- o <u>Populated Places</u>

  Actual outlines shall be shown when the shortest dimension of the built-up area exceeds .15 inch, otherwise a circle shall be used.

Sample generalization and portrayal actions, extracted from the control base and compiled base manuscripts for ONC 347 chart, are presented in Figure II-2.

Item 1 - drainage portrayal change from double line to single line.
Item 2 - line generalization of coastline.
Item 3 - line generalization of centerline stream.
Item 4 - shifting of railroad and road away from coastline.
Item 5 - shifting of road away from railroad.

Compilation consists of keying a matte projection copy to the control base manuscript. A selection is made of base features, including roads, railroads, drainage, boundaries and miscellaneous cultural features. The selected features are lifted and color coded onto the projection copy.

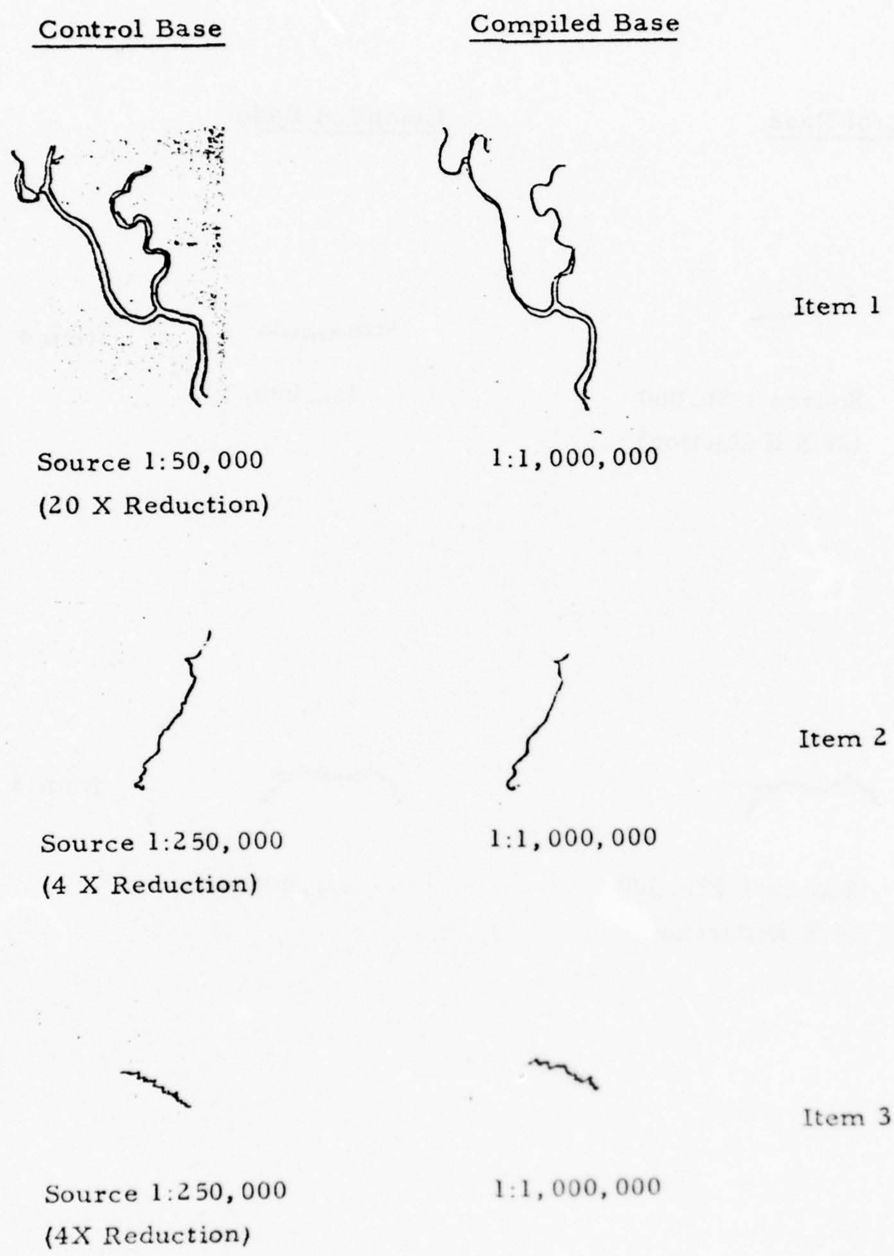


Figure II-2 Examples of Cartographic Generalization
(Page 1 of 2)

Control Base | Compiled Base

Item 4

Source 1:50,000
(20 X Reduction)

1:1,000,000

Item 5

Source 1:250,000
(4 X Reduction)

1:1,000,000

Figure II-2 Examples of Cartographic Generalization
(Page 2 of 2)

h. Compile Contour Manuscript

(1) Inputs

Paneled Contour
Projection Manuscript
Specially-Selected Source Maps

(2) Process

The contour manuscript is compiled from the paneled contour manuscript or control base manuscript. Compilation consists of keying a matte projection copy to the appropriate manuscript. The contour interval is selected according to the specifications of the particular chart series and the type of terrain in the area. If the source material contains contours in the metric system, a conversion to feet is required. Selected contour lines are then traced on the projection copy.

i. Compile Names Overlay

(1) Inputs

Base Manuscript
Source Maps
Gazeteers

(2) Process

The names manuscript compilation can be separated into: (1) selection of those features which require naming, and (2) application of the correct names to the selected features. The cartographic compiler selects the features to be named. Feature names are extracted directly from the compilation source if BGN approved. If not, a geographic names specialist supplies the accepted names when names source requires interpretation, translation and coordination with BGN lists.

For the selection of places and features to be named, the compiler keys an acetate overlay to the base manuscript. Those features which the compiler selects to be shown on the final chart will be identified by symbol and/or location on the overlay. The approved names are added to the overlay beside the identifying notation. When required,

the names overlay and ozalid copy of the base are sent to the names specialist for the application of names, not available to the compiler.

The names manuscript is returned to the compiler for review, after which it serves as input to the Automatic Type Placement System (ATPS) for final positioning, type setting, and plotting of the names color separations.

j. <u>Compile Significant Checkpoint/Intelligence Annotation/RSAC/Feature Overlays</u>

(1) <u>Inputs</u>

Photographs
Intelligence Documents
Source Maps
Base Manuscript

(2) <u>Process</u>

The significant features overlay depicts and describes those features which: (1) are readily identifiable because of size, location, shape, or (2) have particular value in strategic or tactical operations. Compilation involves selection, verification, and portrayal of the features. Selected and validated features are portrayed by pictorial symbolization. They are positioned by the pull-up method from maps or charts, by coordinates, or by photography.

k. <u>Compile Aeronautical Overprint</u>

(1) <u>Inputs</u>

Airfield Plotting Record
Obstruction Record
Flip Enroute Chart and Supplement
Planning Data and Procedures Manual
Visual Aids
Base Manuscript

(2) Process

The compiler sends a mylar positive copy of the base manuscript to the aeronautical information specialist for preparation of the aeronautical manuscript. Information shown on the aeronautical overprint depends on the speicfic chart product although generally includes: airfields, obstructions, restricted airspace, navigational aids, visual aids and isogonics.

The manuscript is reviewed for accuracy and completeness by the Edit Section. JOG Series Charts receive a review by the Special Projects Area. The aeronautical overprint is then sent for negative engraving. While negative engraving is being performed, aeronautical specialist retains a "blue line" copy of the overprint, which is updated when new relevant information is received. Seventeen days prior to reproduction, the updated "blue line" is forwarded for update of aeronautical data on the negatives. This allows the chart to be published with the most current aeronautical information.

1. Prepare Pictorial Relief

(1) Inputs

Contour Manuscript
Base Manuscript

(2) Process

Pictorial relief representation can be separated into preparation of: (1) elevation tint information, (2) level area overlay, and (3) shaded relief manuscript.

The elevation tints consist of a color coding system for differentiation of elevation levels. From the specifications, the compiler determines elevation levels for the specific chart; he then notes the intervals on the contour manuscript.

The level area overlay consists of an outline of areas with a maximum slope factor of three percent from the surrounding terrain. An analysis is made of the contour and base manuscripts to determine the appropriate level areas. A clear mylar sheet is keyed to the contour manuscript and the selected areas are delineated.

The shaded relief manuscript is compiled by a terrain emboss technique. Source materials required are: (1) level area negative, (2) base manuscript negative, and (3) contour manuscript negative. The compiler supplies Photo Services with source materials. The base, level area, and contour information are photographically exposed on both sides of a composite loftrite material. The compiler then determines the desired amount of vertical exaggeration and produces a relief model by using steel tools to protrude and depress mountain and valley areas respectively, on the loftrite. Individual models are controlled to the base detail.

The relief model is painted gray and sent to Photo Service, where a continuous tone negative is made. While the photograph is being taken, a northwest light source is exposed over the model, resulting in a shading effect to the southeast of mountains. The individual model negatives are then mosaiced to a master base by the compiler. After being touched-up, the complete model is sent to Photo Services for final half-tone negative preparation.

m. Compilation In-Process Inspection

(1) Inputs

Compiled Manuscripts and Overlays

(2) Process

After each manuscript or overlay is compiled, it is checked for critical items pertaining to the selection and portrayal of specific features. Items such as completeness, accuracy, generalization, etc., are usually checked. If any discrepancies are discovered, they are resolved with the compiler and required changes are made.

3. Special Process Considerations

There are two major production elements concerned with performing cartographic compilation. While each element follows the process flow as described above, one area has unique photographic compilation functions not required by the other. The limiting or differentiating factors are the security classification of source materials, and the availability of accurate graphic source materials. The unique classification restrictions preclude any overlapping or sharing of this material between production elements. Therefore, careful consideration must be given to the unique nature of both the materials and their restricted utilization and the effects of this on the efforts to automate the compilation process.

a. Cartographic Intensification

The restricted compilation production area regularly performs a process of cartographic intensification. This can be defined as the utilization of multi-use photogrammetric bases as the major input source into a standard DMAAC product. The process requires the verification and feature classification of cartographic information, presented by the photogrammetric process, and the possible intensification of that information both in number of features and currency of information. This must then be converted to a basic chart manuscript/overlay package suitable for color separation. The intensification and conversion are dictated by the requirements as given in the product specification. The process combines the use of photographic, cartographic and textual sources. The extraction, comparison and classification of features and information to be shown on the final graphic may require direct common scale comparisons of cartographic and photographic sources. An integral part of this process is the creation of, or revision to, the associated overlays with particular emphasis on radar prediction overlays and the intelligence annotation overlay for the Series 200 USATC and JOG-R graphics. These may also require intensification of supporting base detail. Specific features associated with the target program must be positioned to the geographic projection to a high degree of accuracy. It is considered routine that the information added

may be extracted from late date sources only available since the compilation of the basic photogrammetric base.

b. Maintenance

The emphasis on the compilation and publication of new graphics will continue to decrease. This relates to first edition of first-time coverage of a particular chart series. Maintenance of existing graphics will become a major production consideration. Present standards related to a maintenance criteria place the greatest emphasis on currency. Existing litho's for which there are color separation negatives are reviewed against the latest source data (see paragraph III-B-1-b). Once the areas of change have been identified, the necessary manuscripts and overlays are prepared. These may range from correction overlays to a complete redrawn manuscript. The maintenance function applies to both of the cartographic production elements; thus there is a breakout of source material limitations as previously defined. The maintenance function does not indicate a change in complexity, accuracy or completeness of the compilation process. It may reduce in scope the actual number of features compiled or revised, but there is not reduction in the emphasis on the requirements. Even the decision that, for example, 90% of the features currently shown on the existing litho, do not require revision, may take as much analysis as if it were first being compiled. There is no lessening of the accuracy of manuscripts or overlays supplied for negative preparation.

4. Current Problems

- The current methods of compilation are heavily dependent upon scale changing via photographic lab. enlargement and reduction. The integrity of projection devices used for map to map and photo to map comparisons has been questioned and has become the lesser used technique, thereby requiring more photo lab. support.
- Basic compilation, whether new base or revision, are presented in colors selected to differentiate to the

engraver any lines that tend to coalesce. This color differentiation is also supported by the use of symbology duplicating the final portrayal on the printed map. For example, a trail is not only shown in a unique color but is shown as a dashed line approximating the finished symbology. Cross ties are shown on railroads and differentiation is made as to the place where the number of tracks change. This symbology philosophy is not inadequate, per se, but it does encumber the compiler and tends to add to the man-hours spent in producing a manuscript.

- The delineation of cartographic features from aerial photographs is performed monoscopically. Therefore, features extracted in mountainous areas are subject to errors due to relief displacement. This error in positioning makes direct comparison of maps vs. photos subject to misinterpretation in areas of high relief.

- There are requirements for detailed photo interpretation at high magnification to satisfy certain medium scale compilation requirements; e.g., radar prediction information, overpasses, bridges, etc. The transfer of information from photo to map, particularly positioning, is normally performed by estimation of feature size, relationship and position due to a lack of effective transfer equipment.

- The quality control checks performed require the senior cartographer to randomly sample the processes performed by the compiler. This includes an assessment of alignment accuracy, positioning, etc. The time required to perform an effective quality check limits the tests that could be performed.

5. <u>Timing Considerations</u>

Production of charts requires significant expenditures of man-hours and calendar days. DMAAC maintains a set of production standards for each major product type. To provide a framework for establishment of design requirements for an automated compilation system, a summary of

a production for a sample product is presented below. The process steps identified by "*" are those most applicable to a cartographic compilation station. In summary, the sample product required approximately 1450 man-hours to compile and prepare for color separation. This was done within 248 calendar days after assignment.

Product: JOG-A/G (Sino Soviet)
Production Method: In-House
Date: 29 November 1974

Work Seq	Work Sequence Title	Stand. Hours	Stand. Start	Days Stop
5	*Obtain & Evaluate Source	52	1	30
10	Computations	1	12	20
15	*Preparation & Inspection Data	6.5	12	100
20	Gerber Plotter	5	20	49
25	*Compile	420	31	143
30	*Comp. Quality Review	40	31	156
35	? Photo Lab Support	24	31	143
40	? Photo Lab Support	40	31	143
45	*Sanitization	12	156	158
50	Tint	8	156	158
55	*Finalize R4N	16	159	172

*Process to be considered for advanced system applications.

? Possibly eliminated by advanced system.

D. Source Assessment/Data Extraction Analysis

1. Background and the Problem

The source assessment and data extraction processes were initially viewed as being performed by a combination of current techniques/processes and the advanced compilation system. Specific areas which would support "source assessment and data extraction" would include: the current research function, job planning function, photographic services, graphic digitizing, and interactive graphic compilation processing. Visual assessment of graphic materials would be performed at various stages of the compilation, with detailed feature assessment being performed subsequent to rectification and transformation of graphic source to a common reference frame principally in the form of plots and interactive displays at the interactive compilation system. The system thus would provide for detailed assessment and interactivity with selective source files.

The data extraction of high volume feature information was expected to be performed by production digitizing systems, while augmentation to the compilation base with low volume feature information from supplementary sources, could be performed directly at the interactive system. Direct input and assessment of supplementary sources at the interactive system could support effective update/revision types of production jobs.

The client requested that the "source assessment and data extraction" problem be closely examined. During the analysis specific views concerning the "source assessment and data extraction" problem were discussed with client personnel. Major points which affected the analysis included the following:

- o Definition of techniques/software/hardware which could support the source assessment function, could be encompassed by the graphic compilation subsystem or possibly a new subsystem, whichever is appropriate.

- The primary problem is the capability to effectively assess graphic source against another graphic or against existing digital feature data. Ideally the compiler could view selective, multiple sources against selective digital data; although the client subsequently stated that the ability to view a single graphic source against digital data would be sufficient.

- Error induced by the use of reflecting projector equipment for preparing lifts of feature information from source graphics is probably undesirable for high quality compilation work. Distortion, due to projection system differences of the source vs. the compilation, is variable depending on the scale reduction factor applied to the source material.

- The current necessity of relying on photographic and rectification systems for scaling and rectifying of source maps and imagery is costly and very time consuming.

- Commitment of resources to perform conventional digitizing of graphic source materials for a specific product is viewed as being too costly, in that only a small percentage of the resultant data would actually be exploited for that particular product.

- Once the compiler has performed his assessment of a source and decided what feature information is required for further compilation processing, conveying specifically what information to digitize is anticipated to be a problem. The client expressed the view that "ideally the compiler could immediately tag the feature for digital extraction (e.g., ALF, raster scan, etc.)."

- Graphic sources to be assessed include the following "current" types of materials (reference Appendix C - Source Matrix for specific sources, scales, projections):

  - maps and charts - various scales, projections, areas of coverage, color format media (e.g., litho or micromasters).
  - compilation materials (MUMS and related graphics) - generally consist of a definite group of scales and projections.

- orthophotos - various scales and areas of coverage, may be available.
- imagery - stereo, panoramic, or spot photography

o Assessment is preferably performed at the product compilation/ revision scale; and normally performed by sub-areas (i.e., load adjustments and comparisons) of the total product area.

o The client is not convinced that distortions due to different map reference frames (i.e., projection systems) and distortions inherent in aerial photography would necessitate transformation/ rectification processing for the source assessment function. The thought is that scaling and local adjustments would normally allow sufficient assessment capabilities.

Assessment and usage of a variety of source materials is a time-consuming and awkward step in today's product compilation. The source assessment process requires the compiler to:

o assemble all identified source materials;

o review the extent of coverage and information content of each source; and

- attempt to visually correlate feature information between multiple sources and compilation manuscripts

The process is, of course, extremely difficult to manually perform because of the sheer number of graphics; also the process may lack precision and credibility when the sources have different formats (e.g., scales, projections, etc.). The compiler frequently relies on photographic services for scaling and rectification of source materials prior to detailed assessment and feature extraction; also reflecting projectors with scaling capabilities are used for viewing, comparing, and extracting selected feature information.

2. <u>Analysis of Technical Requirements</u>

Several technical requirements and goals were identified which, if achieved, would provide a high level of capability. These requirements and goals included:

- Transformation and/or rectification of graphic source materials to a common reference frame is desired. Preferably the reference frame would be the compilation projection and scale.
- In addition to graphic sources, some digital data may also be available and will require transformation and scaling to the compilation reference frame.
- Viewing of sources must allow for selection and suppression of individual sources. Ideally the system should allow for some level of display/suppression of selected feature information contained on one source. This capability would be most useful when the user encountered excessive feature density.
- Presentation of digital and/or graphic sources must be precise enough to provide a basis for feature comparisons and subsequent decisions concerning usage of individual sources. While no specific "accuracy requirements" have been stated for source assessment it appears that certain of the following compilation accuracy standards* should be applicable:

*DMAACINST 8560.3

- Rectified Photography oriented locally: .020"
- Fit of reduced film positives of source or pull-ups to projection:
  - -- In first direction - exact or undersize not to exceed .005".
  - -- Perpendicular to first direction - exact or undersize not to exceed .050".
- Vertical reflecting projector transfer and freehand transfer .020".
- Direct lift of detail from source maps and/or control base to compilation manuscript .010".

Based on the analyses conducted it appears that at least three major steps, illustrated in Figure II-3, will be required to perform the "source assessment and data extraction" process. The three steps are:

Step 1 - Source Coverage Analysis

Step 2 - Comparative Source Content Analysis

Step 3 - Source Content Extraction

Step 1 - Source Coverage Analysis

Purpose

To examine and assess the geographic coverage and limits of various source graphics and digital data files.

Inputs

o Location Parameters - geographic boundary locations of each source should be known, relative to the compilation reference frame. If such information is not precisely known for a piece of source material, that source data would require orientation by the user based on recognition of features with known absolute or relative locations. Source materials whose locations are not precisely known would be handled as "floating source files."

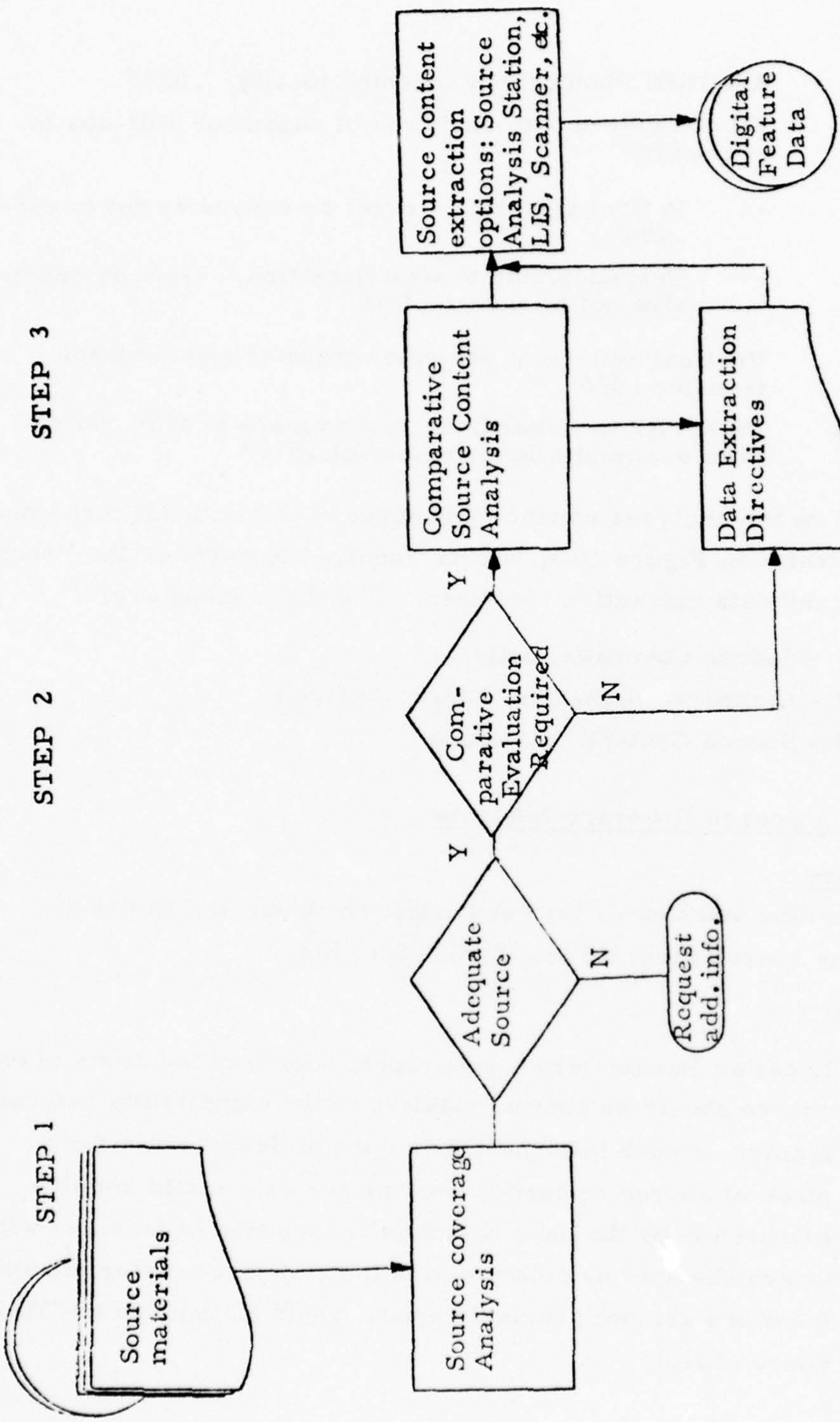


Figure II-3 Source Assessment & Data Extraction

- Source Identification - specific items of importance would be maintained for each digital and graphic source:
  - source type/format
  - location parameters
  - scale
  - producer
  - projection
  - content
  - currency date
  - accuracy evaluations (PE)

Processes

- Coverage Display/Plot - based on location parameters of each source, area coverage of selective combinations of sources would be plotted or displayed at the compilation scale and projection. Each source boundary would be uniquely identified for correlation with "Source Identification" information.
- Preliminary Assessment - cartographer would perform assessment of source coverage and associated content adequacy. Plan for further compilation actions would be determined: source coverage is not adequate to comply with product goals--currency, accuracy, coverage; further detailed assessment is required to evaluate source compatibility and information to be extracted from individual sources; graphic to digital conversion can commence for specific graphics and specific information (e.g., roads, drains, etc.); and/or digital compilation can commence over specified area(s) of compilation and/or selected feature information.

Output

Compilation Plan

- Sources to be used for further compilation work.
- Deficiency of source information.
- Requirements and schedules for other compilation subsystems.

Step 2 - Comparative Source Content Analysis

Purpose

View individual and composite digital and graphic sources such that visual correlation of source contents (i.e., features) can be achieved with sufficient accuracy to determine content adequacy, potential conflicts of feature information, and/or feature change and update requirements.

Inputs

- o Same as Step 1
- o Selected source coverage plot
- o Digital files of selected digital data over the product area
- o Selected graphic sources

Processes

- o Transformation and scaling of digital feature data.
- o Preprocessing of graphic sources, as dictated by techniques employed.
- o Selection and display/plot of digital data and graphics source information.
- o Perform comparative feature evaluation.
- o Develop compilation plan.

Outputs

- o Source usage assessment
- o Compilation plan

Step 3 - Source Content Extraction

Purpose

Subsequent to source assessment the goal is to extract selected feature information from those sources for subsequent compilation processing. Thus the end result of the "source analysis" is: identification of sources selected for further compilation; and either extract digital feature information directly or identify feature information to be converted by digitizing systems. If the data extraction task requires low volume digitizing the process could be directly performed at the Graphic Compilation Subsystem.

Inputs

- Compilation Plan
- Source Materials

Processes

- Standard processes if conventional digitizing or scanning systems are used.

Outputs

- Lineal files of selected cartographic feature information by source.

E. Compilation Proofing Analysis

1. Introduction

The Government requested that the compilation proofing function be examined more closely to determine and define the methodology of and system requirements for proofing in the advanced compilation environment. The analysis presented below covers description of the function, topics discussed with DMAAC personnel, and analysis of technical considerations and approaches.

2. Background

The current proofing function performed by DMAAC during product compilation consists of a number of techniques and procedural conventions. The compiler strives to produce a quality product by attempting to comply with compilation quality control and accuracy standards (see Appendix B). In addition, the compiler maintains all source and compilation materials used throughout the job, thus providing a graphic record of the compilation steps and associated processes. A set of critical quality items are defined for major compilation steps and are used by senior compilers or quality control personnel as a checklist for product proofing.

In summary the proofing function is achieved through the use of compilation quality standards, maintenance of all compilation materials, and manual reviews at critical compilation steps.

PRC's initial view of the proofing function, and concept for performing such, was, generally the same approach as employed in the manual system, with addition of a few system techniques which embellish the effectiveness of proofing. Specifically: quality control standards would still guide the compiler and any software processes concerned with feature shifting, generalization, etc., graphic plots could be generated at selected intervals for off-line review and verification; and checklists would be used for reviewing critical compilation actions.

DMAAC's response to PRC's "Compilation Processes Working Paper" reflected their views pertaining to the proofing problem.

"The quality control checks performed require the senior cartographer to randomly sample the processes performed by the compiler. This includes an assessment of alignment accuracy, positioning, etc. The time required to perform an effective quality check limits the tests that could be performed."

Based on discussions with RADC personnel, PRC's views and concepts of the proofing problem were compatible with DMAAC's views. The primary thrust of DMAAC's request for the expanded analysis therefore appeared to center within clarification and expansion of proofing concepts and techniques planned for the advanced compilation system, with specific interests in automated tools which could support more effective proofing and associated hardware/software implications.

3. Technical Considerations

a. Discussion of Requirements

Requirements for accomplishing the proofing function can be viewed as:

- detection of errors or possible error conditions and/or providing necessary vehicles to the compiler/reviewer which would allow him to perform detection or verification; and
- performance or identification of the necessary corrections.

Graphic presentation to the reviewer must convey two information items: specific feature type, and specific feature location. The type of feature can be presented by a number of symbology techniques, including: line size, line color or shading, or line symbol patterns. Additionally, the compiler frequently uses textual annotations to clarify or describe specific characteristics of a feature.

The feature location is also specifically checked to ensure that shifting or generalization of features are consistent with compilation tolerance standards (Appendix B).

b. Technical Approaches

Approaches considered for performing compilation proofing consisted of a number of combinations of software, hardware, and procedural techniques. Three major areas and sample proofing techniques are discussed below.

(1) Compilation Statistical Record

One of the proposed ingredients of the advanced compilation environment, which can support the review processes, is statistical records of pertinent compilation events. Pertinent to the proofing process is information items such as:

- Identification of original sources; sources used and extent of use; and coverage plot of selected sources.
- Feature information extracted from each source.
- Compilation actions
  - number of features shifted.
  - number of feature segments realigned because of congestion.
  - number of features shifted by an amount greater than a specified threshold.
  - extent of line generalization applied to feature groups.
- Compilation working file summary.
  - number of features by group.
  - lineal inch and/or data point count.
  - sub-area density of features (does feature density conform to desired visual impression?)

The above sample items could be maintained with the compilation working file and easily presented to the compiler for his own review of progress as well as presented to review personnel for in-process proofing. The compilation statistics should be kept for pre-graphic batch processes, as well as interactive compilation processes.

(2) Automatic Support to Error Detection

This area of support to the proofing function would consist of a set of hardware/software tools for detecting possible compilation errors. It's recognized that the compiler has the license to select and adjust feature information, within certain guidelines, to properly represent an area for a given product; and therefore it is proposed that the system detect and flag possible error situations to be reviewed and verified by cartographer personnel. Given enough cartographic logic and resulting software the system could probably detect or verify a wide range of compilation actions and product contents. Basically, consideration should be given to developing those software/hardware tools which are effective in helping the compiler/reviewer detect possible error conditions which are critical to the end product . Sample error detection tools might include the following:

- Feature Realignments or Shifts - the user could request the system to plot or display only the subset of features which were shifted by an amount exceeding a specified distance (e.g., shifted more than compilation tolerance standards).
- Accurate Terrain Representation - a critical information item for aeronautical or oceanographic navigation is terrain elevation and water depth representation. To verify that the terrain data is properly presented the system could plot or display all terrain features (i.e., contours and spot elevations) higher than a specified elevation. The user could thus verify that the spot elevations conform with associated contours and that the highest elevations are properly identified. Consistency in contour elevations could be verified by:
  - displaying profile lines for selected vectors
  - automatically checking for consistent contour intervals

(3) Graphic Displays and Plots

One of the most effective proofing tools will be graphic displays and plots. In general, the Advanced Compilation System will be capable of producing graphic displays/plots of selected feature information and present such information in a variety of symbolized formats. The frequency of producing proof plots should depend upon the complexity of the job and cost-effectiveness associated with frequency of generating review plots. Contents and format of the graphic plots can vary from composite plots of "before and after" feature information to plotting of only feature information changed subsequent to the previous plot/review step.

Another consideration to support proofing is composite displaying of the digital compilation file against original source graphics. This proofing step would logically be performed subsequent to source assessment and data extraction and prior to interactive compilation. This step would provide verification that correct and sufficient feature information was extracted from appropriate source materials. Software/hardware capabilities developed for "source assessment and data extraction" function could also be applied to this phase of proofing.

4. Conclusions and Recommendations

a. Conclusions

o Proofing should be achieved in the advanced compilation environment by a combination of hardware, software, and procedural techniques, specifically including:

- statistical reports describing the digital compilation activities.
- system aids to support compilation review and proofing functions.
- graphic presentation of selective digital feature information for review and/or comparison with source graphics/intermediate compilation graphics.

- Proofing function has some distinct similarities as the source assessment function, in that one of the key requirements is for the user to be able to compositely view source graphics against selected digital feature information.

- Hardware System Implications

  Graphic Plotter - required to produce accurate, proof quality of graphic plots. Plots must include necessary symbology to allow the cartographer to quickly differentiate feature groups.

  Graphic/Digital Display System - could support the proofing function if other uses (i.e., source assessment) of such a system could help justify its development.

- Software Implications

  Proofing Aids - could require an application program for each major type of interactive proofing aid.

  Symbolization Software - various levels of symbology are expected to be available to direct the display and plotter systems to generate line, point, and alphanumeric symbols required for visual review and proofing.

  Feature Files - definition of feature file formats should allow for maintenance of file summary data and special tags (e.g., deleted, shifted, etc) for individual features.

  Statistical Reports - both the batch processing and graphic compilation systems should include comprehensive process recording and reporting mechanisms.

b. Recommendations

PRC proposes that proofing within the advanced compilation environment be achieved by employing combinations of hardware, software, and procedural techniques. The proofing processes should be exercised at different steps during the compilation and to various depths depending on the type and complexity of each production job. Specifically, system tools to support proofing should include:

- Statistical reports concerning processes, user action, and file contents.
- Graphic proof displays and plots.
- Special software aids for interactive proofing of critical compilation facts.

III. BACKGROUND SYSTEMS & TECHNOLOGY ASSESSMENTS

A. Introduction

The primary purpose of this section is to present a review of current compilation systems and, in general, an assessment of required hardware components which are commercially available.

B. Background Systems

A review of experimental cartographic compilation systems was conducted for the purpose of benefiting from existing research and development. The three systems examined were:

- o Digital Input/Output Display Equipment System (DIODE)
- o Experimental Compilation Console (ECC)
- o Computer Aided Map Compilation System (CAMC)

The original plan was to perform a more comprehensive evaluation of each of the systems, although due to problems of accessibility, scheduling, and/or operational status, full evaluations were not performed. The review team observed sample capabilities of the DIODE system and cursory line edit functions. The CAMC system was reviewed through documentation and discussions with Dr. A.R. Boyle of the University of Saskatchewan, the developer of CAMC. The ECC system was tested by the review team, and therefore the evaluation of this system was more comprehensive than either the DIODE or CAMC.

1. Systems Description and Observations

This section presents an abbreviated description of each system and major observations.

a. Digital Input/Output Display Equipment

The Digital Input/Output Display Equipment (DIODE) is a system being developed by the Engineering Topographic Laboratories (ETL) for use in editing cartographic data. The DIODE system was reviewed as part of the experimental compilation system study because many of the same functions which manipulate data for editing purposes can be applied to the compilation processes.

(1) Functional Capabilities

- o Feature identification in form of list on CRT, line printer, TTY, and symbolization on CRT's.
- o Feature header modifications for any or all of feature header items.
- o Deletion of points and of features on a window, an entire linear feature throughout map, or any portion of a feature.
- o Insertion of new points or linear features including isolating features, new features that join to existing features, or new feature segments to replace a previously deleted portion.
- o Connect endpoints of two features with straight line segment.
- o Shift position of entire feature in response to TTY commands.
- o Automatically shift a feature to match endpoints of a second feature (in lieu of a connect operation).
- o Join operation where a line feature is forced to connect to a designed intermediate or endpoint on another feature (road or stream intersections where tags need not be the same).

- o Replace operation whereby a portion of a feature is automatically deleted and replaced by new data drawn by operator.
- o Restore any deleted data back to original state.

There are plans to extend the set of existing functions before DIODE is placed into an operational environment. At present, there is no documentation available as to what the additional functions will include.

(2) Observations

The physical relationship of the CRT's the digitizing table, and the functional keyboard is good from a human factors standpoint. It was also found that the 3X magnification of the LUNDY 32/300 was convenient for a feedback device for detailed line manipulation being performed on the digitizer.

The duplicity of hardware, i.e., four keyboards and three CRT's, offers an excellent opportunity for comparison of these devices in their use in cartographic work.

The major problem area with DIODE is the amount of software overhead due to the extensive hardware being used. The ultimate effect of this overhead is cost. The estimated cost for the first station is expected to be 400K for the present configuration. However, it is expected that the operational system will be only a subset of the present configuration.

The existence of both LUNDY 32/300 and the CPS Color CRT, side by side, gave a very good comparison of the use of gray shades versus color for symbolization. The LUNDY 32/300 is an (X, Y, Z) vector refresh CRT where the Z-axis is gray shade. The CPS scope is also (X, Y, Z) oriented where the Z-axis is one of four colors. The variable gray shading appeared to be as effective as the color variation for symbolization, at least when a low volume of data is displayed on the screen.

The LUNDY 32/300 is an interesting CRT in that it has rotation hardware which allows for scaling or rotation of a given display without alteration of the buffer contents i.e., by modifying the scale or rotation reigster contents. This CRT also has a variable hardware implemented refresh rate which allows the user to reduce flicker (up to hardware limits) by adjusting the refresh rate from the CRT controls.

In final analysis, a production system will probably require fewer hardware devices than currently provided within DIODE. For instance one configuration of the final version of the DIODE system would contain one alphanumeric keyboard and two CRT's one CRT being a refresh type for low volume detail; and the second being a storage type for high volume data. This would reduce the per-station cost.

b. Experimental Compilation Console

The Experimental Compilation Console (ECC) system was design as a testbed for the implementation of interactive compilation functions. The ECC was implemented as an extension to the Cartographic Digitizing Plotter (CDP) system. One of the basic limitations of the antecedent CDP system had been the extremely long plot times for large data files. The ECC provides a quick-look capability which allow the user to view large data files through the use of a CRT. Once problem areas have been located on the CRT, the CDP stylus can be automatically driven to the associated point on the chart. CDP edit functions can then be applied in the same manner in which they were originally implemented.

(1) Functional Capabilities

- o Select Symbols
- o Select Feature
- o Select Area
- o Display and Modify Feature Header
- o Delete Feature
- o Transfer Graphic Cursor Position to CDP Stylus Position

- Position Contour Label
- Position Point Symbol/Alphanumeric String
- Select Scale
- Move Window
- Position ECC Cursor
- Join/Join-Close

(2) Observations

The ECC system is an experimental system and as such has provided insight into the use of interactive devices for cartographic editing and compilation. The strong point of the system is the extract and plot speed. Feature selection through use of the plot file is fast enough to satisfy user requirements. The system is not suited for production in its present state. The primary production drawbacks are due to the lack of feedback to the user of data such as window number, feature class, scale, and the inflexibility of the function calling sequence when changes in screen viewing area, scale, and cursor movement are required. The addition of the capability of the PLOT file to reflect every change made to the CDP file would also move the existing system significantly closer to being used as an operational test bed. Another area requiring improvement to satisfy true compilation requirements is feature symbology. The ECC defines a feature class by placing numeric characters along the feature line, which is awkward to quickly recognize as feature density increases.

The use of an interactive digitizing plotter (i.e., CDP) is a unique feature of the ECC. The principal advantage in the use of this device is the ability to use it for detailed editing and plotting for immediate verification. The CDP provides a .001 inch resolution which is a factor of 10X better than any CRT used on other experimental systems. In addition the user can obtain a hard copy plot during run time which he can annotate to provide better control. Unfortunately the plotting speed has been unacceptably slow.

The hardware cost of the present system is relatively high. The requirement for both a PDP-15 and PDP-9 and the CDP could probably be reduced if the system was rewritten for use in a production environment.

The ECC is an experimental system. Much of the software has not been fully tested. In addition, the system has to some degree "grown like Topsy" because several contractors have modified the system for other technical developments as RADC's requirements have changed. As a testbed, the ECC is successful. It will be possible to use many of these concepts in the design of the Compilation Station.

c. Computer Aided Map Compilation

The Computer Aided Map Compilation (CAMC) system is a product of the University of Saskatchewan's Graphic Systems Design and Application Group. The CAMC system was designed to support the compilation of hydrographic charts for the Canadian Government.

(1) Functional Capabilities

The cartographic functions which are documented as being implemented on CAMC include:

- Line Symbolization
- Header Modification
- Names Placement

- o Point Symbol Placement
- o Line Manipulations
  - Completely erase a line
  - Clip the end of a line
  - Erase the middle part of a line
  - Add a new line segment into the erased section above
  - Add a part on end of line
  - Add a complete new line
  - Reverse direction of a line
  - Change coordinate points in a string
    - -- Change point location.
    - -- Erase a point.
    - -- Add a point in a string.
  - Extract part of a line and create a new header for it
  - Display start and end of lines
  - Join lines end to end
  - Join lines end to end but smooth backwards
  - Join line to another at T-join
  - Join line to another at T-join but smoothed
  - Form a polygon of lines

(2) Observations

The CAMC system has made heavy use of graphic CRT technology. In other existing experimental compilation systems, the CRT has been used primarily as a feedback device; in the CAMC system, the CRT is used to initiate and control cartographic compilation functions.

The CAMC system uses a syntax language for the man/machine interface. Dr. Boyle, Project Leader, indicates that the user has been able to quickly learn the CAMC language structure, and that this structure is versatile enough to control all cartographic functions.

The CAMC system contains a number of new innovations. One of the most significant is the use of line symbolization of display data. There are three classes of line symbology:

- o dotted or dashed lines
- o wide lines through use of interlinked polygons
- o lines of variable intensity through the use of linked partial polygons

The ability to widen lines, especially when scaled graphic data is being displayed on the CRT, is especially important to proper line positioning relative to the final compiled chart.

Another innovation is the extensive capabilities for alphanumeric character placement. The CAMC provides for not only multiple type styles and scales, but also for conformal text string positioning. Dot matricies are used for CRT representation.

A third innovative idea is the use of very small scale displays of the cartographic data for defining of area extractions. For example, if the user wanted to compile a JOG of the Rome, New York area and the data base included the entire United States, he might request a display of the entire data base, and position the cursor in the general area of Rome, New York. He would then call for a larger scale display centered on the cursor position. He would reiterate the selection process until his display was at the desired position and scale.

The CAMC system requires a very limited amount of hardware. The prime components are PDP-8e's, Tektronix CRT's, and associated secondary storage. The hardware costs are relatively inexpensive. Since the CAMC system has not been observed, it has been impossible to ascertain the effects of the limited hardware or software costs and response times, although reports have been favorable in both areas.

Possible drawbacks to the CAMC appear to be: 1) lack of suitable lock-on for feature edits, 2) limited display dynamics due to use of a storage CRT, 3) alphanumeric placement capability was potentially useful but was limited due to write times required by the storage CRT, and 4) the use of the ASR 33 teletype as an input device was somewhat of a human factors problem.

2. Summary

The DIODE, ECC, and CAMC systems represent a full spectrum of complexity and cost. All three systems perform the same basic functions; that is, display and modification of digital feature files.

It should be emphasized that all three systems represent various levels of experimental development, and as such, it is difficult to measure their potential effectiveness in production.

A summary of the major compilation hardware components and characteristics is presented below.

			Resolution	Spot Size
DIODE	CRT's	ARDS 100B	10 mils	15 mils
		LUNDY 32/300	10 mils	15 mils
		CPS	10 mils	20 mils
		BENDIX DATAGRID	1 mil	
ECC	CRT's	TEKTRONIX 611B	10 mils	15 mils
		TEKTRONIX 4002A	10 mils	15 mils
		CDP	1 mil	6 mils
CAMC		TEKTRONIX 611B	10 mils	15 mils
		INSTRONICS	0.4 mils	

CRT resolutions were consisten at 10 mils throughout all systems reviewed. Spot sizes were also constant at 15 mils with the exception of the color CRT which produced a 20-mil spot size. These resolutions and spot sizes appear to be insufficient for maintaining cartographic quality (i.e., 2-mil relative feature position) at 1X scale. It can be shown that a 7X scale is required, in some instances, to achieve cartographic quality of displays on a CRT with the above specifications. A scale factor of this magnitude also appears unacceptable since a 10-inch CRT would display less than a $1\frac{1}{2}$ inch square of chart data. The overall appearance of an area would be lost using only a $1\frac{1}{2}$ inch square area. Therefore, it appears necessary that CRT's with better resolutions and smaller spot size is desired for effective and accurate cartographic compilation.

A basic design philosophy difference exists between the CAMC system and the ECC and the DIODE systems. Both DIODE and the ECC use the CRT's as a feedback device to improve feature selection and verification as a supplemental tool to the digitizer tables. The CAMC system, on the other hand, employs the CRT as the dominant device for performing compilation processes. The digitizer is used only for extensive addition of feature data. One advantage in CRT controlled compilation is the potential for improved man-machine interaction.

The following conclusions have been drawn from observations, or the documentation of experimental results, on the manipulation of very limited data sets in a non-production environment.

- o Lineal symbolization is necessary on the display CRT to eliminate confusion due to density. This symbology may be implemented via color, intensity, or line width.
- o Compilation station should consist of a fast interactive display device for selective viewing of feature information, and an associated graphic table for mounting large graphic plots.
- o The chart and the CRT display should be in a physical relationship such that both may be viewed by the user with minimum change in his position.

- The base manuscript and digital file must be in registration at least to the extent of controlling selection of the area to be displayed on the CRT via the graphic.
- CRT displays are definitely effective in the compilation process for feedback and line manipulation work.

C. Technology Assessments

In order to present a set of viable compilation system alternative configurations, components that could possibly be used to form those configurations must first be identified and assessed. To that end, the PRC/ISC task team conducted an industry search for those devices appropriate to comprising a selection group from which alternative configurations were derived. Assessments of those devices were made individually, and are presented below. Each device is assessed in terms of its role within the system, its major characteristics and inherent trade-off factors, and its proximity to satisfying significant design requirements.

A real world compilation system is, of course, a subset of all available component types; the configuration finally chosen for design most likely will not include every available type of device. However, it is appropriate to present for review here a list of the families of devices studied by the task team, and the general functions of those devices.

The component assessments following the list below is not intended to include each model of every device type currently manufactured; rather it serves to look at representative devices within major device types or categories.

	DEVICE FAMILY		POTENTIAL USE
1.	Display	o	Cartographic features, text and symbology display
		o	Interactive manipulations
2.	A/N Keyboard (associated with item 1)	o	Data Entry
		o	Feature/area specification entry
		o	Compiler responses to queries
3.	Special Functions Keyboard	o	Display modes
		o	Processing commands
		o	Feature manipulation commands
4.	Graphic Digitizer	o	Low bulk feature entry
		o	Coordinate/area locating
5.	Tracking Tools	o	Cursor control
		o	Coordinate locating
6.	Plotter	o	Rapid, full size interim review plots
7.	Graphic Hard Copy	o	Immediate local review of displayed features
8.	Manipulation Generators	o	Hardware driven functions of display scaling, windowing, translation, rotation, and arc/circle generation
9.	Processors	o	Control and distribution of system tasks and communications
		o	Execution of applications programs
		o	Control of display processing
		o	Management of compilation tasks
		o	Communication with system user

(Continued)

DEVICE FAMILY		POTENTIAL USE
10. Magnetic Tape	o	Data input - Batch processed chart files - chart revision data - previously compiled archival data - system image restore
	o	Data output - compiled chart separation files - review plot files - system image save
11. System Control (TTY, etc.)	o	System operator requests, commands, and responses
12. Printout (Line Printer, etc.)	o	Status, exceptions, and statistical reports
	o	Program Listings
13. Storage (Disks, etc.)	o	Chart data files
	o	Programs
	o	Display Files
	o	Symbols, text, and operating libraries
14. Software I/O (Card and Tape Readers, etc.)	o	Applications software development and maintenance
	o	Diagnostic software
	o	Operating software

1. Graphic CRT Devices

a. Functional Purpose

The role of the graphic display is for rapid and accurate display of cartographic feature lines. The graphic display is intended to be the primary interactive device used by the compiler.

b. The Available Technologies

Three distinct categories for display technology are offered by several manufacturers and a fourth category to cover unique and/or unusual devices are considered. The three clear-cut categories are vector refresh displays, video displays, and storage tubes.

(1) Vector Refresh Displays

These devices employ a random screen write capability and must completely re-display the tube image (refresh it) each 1/25 to 1/60 of a second. The screen image is created from a series of strokes (vectors, arcs, or points). Each stroke is created by the display hardware in response to a display instruction that is stored in the display refresh buffer. Display instructions require varying amounts of storage depending upon the length of the stroke (short, medium, or long), the symbolization of the stroke (line, dotted line, dot/dash, etc.), and the geometry of the stroke (straight lines, conic arcs, etc.). Important characteristics of the vector refresh display systems include excellent brightness, availability of relatively small spot sizes, medium resolution, direct use of digital instructions, image dynamicism and availability of color. The image dynamicism directly results from the use of a digital instruction format that may be easily accessed, organized, and manipulated by an associated computer.

The major design parameters for refresh displays are both associated with the total amount of information that may be displayed without flicker. These parameters are: 1) the total number of vectors that may be displayed, and 2) the total vector lengths that may be displayed. As

will be discussed below, both these parameters must be considered in determining the responsiveness of vector refresh displays to the compilation station requirement.

(2) Storage Display

Storage tubes may provide similar capabilities to those of the vector refresh display (they are options on at least one manufacturer's offering) without suffering from the same total information density restrictions inherent in the vector refresh approach. As information (i.e., vectors or points) written on a storage tube does not have to be consistently refreshed, the storage tube requires less memory (no display buffer needs to be resident at all times) and it may display significantly more information than can be supported by a refresh design during its refresh cycle.

As with anything else, the storage tube does not offer this virtually unlimited display density for free and it suffers from other weaknesses. The single most obvious defect of the storage tube is its poor brightness. Other weaknesses not so often discussed, but nevertheless important, are low screen writing rates, inconsistent spot sizes during tube aging, and a complete inability to erase or alter anything less than the entire screen. The low writing rates and lack of dynamicism, when taken together, offset to a large degree the advantages gained with the high density display capabilities.

(3) Video Displays

(a) Direct Digital Video

Video displays differ from both the vector refresh and storage tubes in that information must be transmitted to the screen in a raster format independent of the logical connection between points on a display. Thus, unless special scan conversion hardware is employed (see below) the data must be converted from lineal to raster format (at some expense in computer time) and interactive graphics could become extremely difficult without a backup of an indexed data base

of lineal objects retrievable by a given coordinate and grid value. The strength of video lies with its enormously high data densities (up to 4 million points each with its own gray level or color in a refresh mode). This makes video particularly attractive for image processing (as opposed to line graphics).

Several refresh memories for direct digital video devices are commercially available. All of these systems provide excellent brightness, image dynamicism on a point by point basis, and high density. Some provide for color. The weaknesses of direct digital video are the requirement for extensive software processing support (which slows the system down), a tendency for large spot sizes and lower resolution, and a tendency for higher image distortion. The latter two problems are currently being attacked by manufacturer R/D teams.

(b) Scan Converted Video

Technically, all digital video requires scan conversion. In the direct digital case presented above, the two part conversion (lineal to raster and raster to display) is handled by computer software and memory hardware in that order. In this section we consider the technology whereby hardware performs the entire conversion from lineal (vector) form to raster display. This capability has been implemented through two techniques. One of these techniques has been made possible by recent development of a double ended tube that performs both random write and raster read functions. This tube, the Silicon Storage Tube (SST), consists of a silicon target onto which an electronic image may be written in much the same way as with the common Tektronix or DICOMED storage tube. However, a readout beam scans the target in a raster format once per refresh cycle, and converts the stored electronic image into a video display.

The primary visual characteristics of the SST display are similar to those of a direct digital display - they are bright and they are capable of displaying colors or gray levels. In addition, the SST requires no lineal to raster conversion although interactive graphics would still require substantial support. On the minus side, screen resolution and dot size is still determined to a large degree by the SST device and is not as good as

provided by a vector refresh device. Being quite new, SST image quality has not been completely evaluated.

The second approach, pioneered by RAMTEK, puts special vector and character generating hardware between the computer and a digital video refresh memory, thus providing, in hardware, those services for which software would be required in direct digital systems. The RAMTEK system display differs from that of the SST. All displayed information is generated from dots (not continuous vectors) in a digital pixel format. The image resolution is independent of SST target characteristics and depends only upon CRT parameters and the total number of bits on the refresh memory (1 bit or more (color and gray) per pixel).

(4) Other Devices

As of this time, only one non-CRT optical device has been examined for potential inclusion in the compilation station. This device is a laser film writer and it uses optical back plane projection of a film chip onto which a laser-generated image is recorded. The image is self developing for immediate viewing as the drawing is being generated.

As with the storage tube, the laser device offers virtually unlimited display densities without a capability for partial screen erase. Writing speeds tend to be low although the metric fidelity of this device (resolution and distortion) surpasses that of a CRT-based display. Illumination at the viewer plane is excellent. An auxiliary "refresh" image of lesser quality and low capacity is provided.

c. Commercial Availabilities

All technologies reviewed were represented by at least one manufacturer. In all cases but one, the manufacturer is a well established company; availability of parts and servicing would not be overly difficult.

(1) Vector Refresh Displays

Vendor	Model
Sanders Associates	ADDS 500, ADDS 900
IMLAC Corp.	PDS-1, PDS-4

Vendor (Continued)	Model
Vector General	Series 3
Evans and Sutherland	PICTURE SYSTEM
Adage	GP 400
CPS	8001, 8006
LUNDY	System 32/300

(2) Storage Tubes

Tektronix	4014 (Enhanced)
DICOMED	D36

(3) Video

(a) Direct Video

Data Disk	Anagraph

(b) Scan Converted Video

Princeton Electronics Products (SST)	801
Hughes (SST)	Conographic 12
RAMTEK (Vector/Raster Hardware)	GX 100, GX 200

(4) Other

Laser-Scan Limited	HRD-1

d. Performance Parameters

State of the art, for this review, is defined as the performance of the device with respect to the unique requirements of a cartographic system. These requirements are reflected through the following parameters:

- o Image Quality Area
- o Effective Visible Display Addressability
- o Spot Size
- o Erasability
- o Write speed (in short vectors per second)
- o Brightness

- Distortion
- Maximum information density (in inches per square inch utilizing short vectors that may be displayed over entire screen)
- Maximum high density display area

(1) Image Quality Area

This parameter, in conjunction with the distortion parameter is indicative of the maximum "window" size of a graphic that may be displayed at a given magnification. An area equal to or greater than 10" x 10" (up to 29" x 36") is desirable for the compilation station.

(2) Effective Visible Display Addressability

This variable is a combination of visible screen addressability and image quality area; it is measured in physical distance units (e.g., mils). The effective addressability dictates the minimal distance unit into which a feature locus may be divided. This number is a large contributor to the cartographic precision of which a device is capable. At a scale of 1:1 an effective visible display addressability of 2 mils is desirable for the required level of cartographic precision (relative feature displacement error of no more than 2 mils).

(3) Spot Size

The other major contributor to the determination of cartographic precision is the spot size - the diameter (in mils) of the smallest spot made visible on the display surface of the device. The spot size also dictates the minimal line width that will appear on the display. Spot sizes large in comparison to the effective resolution will detract from the utility of the resolution. Too small a spot size will reduce line brightness and will make finite screen resolution more apparent. Nominal spot size to resolution ratios, as adopted by most commercial designs, are in the range of 2 to 3. A requirement for representing 4 mil lines at a 1:1 magnification for the compilation station would dictate a spot size of approximately 4 mils. A variable spot size would appear ideal for accurately representing the variable line widths found in graphic products.

(4) Erasability

The display device to be used in the compilation station is required to do more than display large density files. It must also reflect changes and edits performed by the compiler to verify the adequacy of the intended product. Thus a reasonable amount of screen dynamicism is necessary - i.e., there must be a capability to change features and feature segments in association with compilation activities. This, of itself, does not dictate that the device must enable display edit of single points or vectors. However, human factors demand that the changes be made in a reasonable amount of time; usually a few seconds. Thus the device capable of editing/changing individual points and vectors has a significant advantage in rapid portrayal of change. However, given a reasonable writing speed and a capability to erase image subareas, software could be employed to rewrite those changed areas in a reasonable time. The larger the smallest erasable area, the higher the write rate requirements.

(5) Writing Speed

This variable indicates the total time necessary to fill the display area with the expected data density. In conjunction with device image dynamicism, it also dictates the typical display generation timing for representation of feature editing and manipulation. The units of "speed" to be used are "short vectors per second." This is chosen because of cartographic feature characteristics which involve much departure from straight lines in a majority of cases. Screen fill time will be estimated by assigning an average vector length of 4 mils to a 1:1 image. Thus, a device capable of 10^6 vectors per second would be producing approximately 4,000 inches per second.

(6) Brightness

Display brightness is primarily a human factors problem; it affects feature discrimination and the ability to work under normal ambient lighting conditions. Eye strain is a significant possibility of

low brightness displays without special environmental conditions. A level of 25 foot lamberts is commonly accepted as a target.

(7) Distortion

Distortions in physical position as a function of display address are common in the CRT. In all but the most expensive (and very small) units, distortion becomes objectionable toward the edges of a display screen. A position error of 1% at a screen address of 2,048 involves a physical dislocation of 20 resolution units (40 mils if a 2-mil resolution is assumed). As relatively near positions will be dislocated approximately to the same degree, this effect will be most noticeable for large highly linear features. State of the art enables distortions of less than 0.5% within the quality viewing area and should be acceptable for this application.

(8) Maximum Displayable Density

This parameter reflects the maximum data density that could be displayed across the entire quality area. It takes into account a variety of display component capabilities and has the advantage of being independent of the display technology employed. It should be measured in units of "inches of incremental data per square inch of display" where an average value of 4 mils per increment is used for vector generating technologies at 1:1. This number reflects the longest refresh time that can be obtained without flicker and/or memory size limitations of the display device. Also incorporated into the parameter is the screen quality area. Larger displays having the same number of total vectors will have smaller values for this parameter.

(9) Maximum High Density Area

This parameter indicates the total display area that would be filled with data at the highest cartographic feature density expected (30 inches/inch^2 at a 1:1 magnification). Four mils per increment was used for 1X.

The parameter is particularly interesting when compared to the quality area (i.e., percentage of display filled). Equivalent

areas filled at magnifications greater than 1:1 (up to 8:1) should also be calculated based upon the following accuracy requirements:

Magnification	Addressable Resolution	Average Vector Length
1:1	2 mils	4 mils
2:1	4 mils	8 mils
4:1	8 mils	16 mils
8:1	16 mils	32 mils

e. State of the Art

(1) Image Quality Area

All available technologies are capable of providing a 10-inch quality area at a minimum. DICOMED displays tend to be somewhat small. The HRD-1 is unusual in that it would allow display of an entire 27" x 39" graphic at a 1:1 magnification. The Lundy CRT is unusually large with a 20-inch square viewing area.

(2) Effective Visible Display Addressability

All devices exhibited a capability for visible screen addressing to at least 10 bits (1024 points). Most technologies were at least twice as good as this:

Vector Refresh Devices

Sanders ADDS 500	1024 across 14 inches = 13.7 mils
IMLAC PDS-4	2048 across 10" = 5 mils (potential upgrade to 4K x 4K or ≈ 2.5 mils)
Vector General Series 3	13 x 14 inches ≈ 10 mils (?) (see note 1)
Evans and Sutherland Picture System	2048 across 10" = 5 mils
Adage GP 400	16 x 16 inches; 6 mils normal (see note 1)
CPS 8006	limited by color convergence (25 mils)

Lundy System 32/300	2048 across 20" = 10 mils (4096 optional but no option cited on resolution)

Storage Tubes

Tektronix 4014 (Enhanced)	x: 4096 points across 15 inches = 4 mils y: 3120 points across 11 inches = 4 mils
DICOMED D36	2048 points across 18 inches = 4 mils

Direct Video

Data Disc Anagraph	480 x 640 across 10" = 16 to 21 mils

Scan Converted Video

PEP 801	1000 lines across 10" = 10 mils
Hughes Conographic 12 (mod. 7217)	1000 lines across 9 inches = 9 mils (y) and 2048 across 12" = 6 mils (x)
RAMTEK GX100	1024 points across 10" (size chosen to maximize results) = 10 mils*

*This is not perceivable with standard 525 video monitors and requires the use of 1000 line monitors.

Other

Laser Scan HRD-1	50K points across 39" = less than 1 mil.

NOTE 1: Vector General and Adage do not specify screen display resolution, only program addressable resolution. However, repeatability is to within 20 mils making a screen resolution of between 5 and 10 mils a lower limit.

It is clear that the HRD-1 is in a class of itself with respect to display addressability. The best of the vector refresh devices and the standard storage tubes come in at around 5 mils. The video devices appear no better than 8 to 10 mils and offer the least precision in the 1:1 magnification range.

(3) Spot Size

Small spot sizes on a CRT is primarily limited by costs. Sizes below one mil are typical in microfilm applications. However, for commercial off-the-shelf CRT's, 10 to 15 mils appears to be the best offered. At least one manufacturer has stated a capability to use a smaller spot size tube in his unit as an unlisted option. The question of variable spot size is still open as no commercial unit offers this option.

-	RAMTEK GX100, Tektronix 4014, Hughes Conographic, Princeton 801, Vector General, Lundy	Approximately 10-15 mils (see note 2)
-	Evans and Sutherland, CPS, Sanders, Data Disc	20 mils
-	IMLAC	12 mils (stated improvement potential to ≈ 4 mils)
-	Adage	15-20 mils
-	Laser-Scan HRD-1	7.8 mils
-	DICOMED	5-10 mils (estimated)

NOTE 2: Digital video system spot size is comparable to, but slightly larger than its resolution. Tektronix spot visually determined to approximately 3 resolution distances. IMLAC and Vector General offer nominal 15-mil spot sizes with optional high resolution tubes to 10 mils.

The HRD-1 again shines in this area. However, even this excellent performance represents twice the thickness of a 4-mil line. DICOMED spot size is based upon limited literature and expectation that a raster image-oriented device would not have spot sizes large compared to resolution. It appears comparable to the HRD-1 specification, but the lower DICOMED contrast would remove some of the advantages of this small spot size.

(4) Erasability

All vector refresh devices have access to each point or vector. The video devices have point erasability but they cannot discriminate as to whether more than one feature passes through a point. As a result, area erase and rewrite techniques would be employed. The storage tubes can erase only an entire screen.

The HRD-1 is still somewhat of an enigma as the available literature does not adequately describe the refresh image capabilities. As far as the main projection is concerned, an entire erase and rewrite would be needed.

(5) Writing Speed

Display System	Vectors/Second
IMLAC PDS-4	10^6/sec.
Vector General	270,000/sec.
Sanders	330,000/sec.
Evans & Sutherland	350,000/sec.
Adage	250,000/sec.
CPS	not available (its write rate is comparable to Vector General units)
Lundy	not specified (appears comparable to Sanders unit)
Tektronix	33,000/sec. at optimum I/O rates and word packing scheme
DICOMED	not available (expected to be comparable to Tektronix)
Anagraph	limited by input rate
Princeton	limited by input rate, of 11,000 vectors/sec.
Hughes	not available; expected to be comparable to Princeton unit
RAMTEK	limited by input rate
HRD-1	a known optimal transfer rate of 3K bytes/sec. limits write rate to under 3K vectors/sec.

It is clear that the lowest writing rates are associated with the devices having poorest erasability. Thus the use of these devices in an interactive environment would be limited.

(6) Brightness

All technologies, except for the storage tube, offer brightness equal to or in excess of 25 foot lamberts. The manufacturers of storage tubes are noticeably silent in advertising the brightness of their tubes in an operational environment. Numbers like four to five-foot lamberts have been seen in the literature.

(7) Distortion

All CRT devices, when kept to their quality areas, meet minimal distortion requirements. The HRD-1 distortion numbers are more like .04% or less making that device the most precise.

(8) Maximum Displayable Density

The HRD-1 again leads the field due primarily to its small spot size and virtually unlimited capacity. The video-based and storage tube technologies are slightly more limited by their resolutions but again provide virtually unlimited capacity. Only the vector refresh devices have limited densities - this due both to writing speed and to memory limitations. With the exception of the IMLAC PDS-4, all vector refresh devices are limited to approximately 10,000 vectors during a refresh cycle of 1/30 second. This translates to approximately 40 inches of data (at 1:1 and 250 vectors per inch) spread over a minimum of 100 square inches (more area would further degrade the values). Thus, with the exception of IMLAC, vector refresh tubes are limited to approximately .4 inch/square inch display density.

In its off-the-shelf form, the IMLAC PDS-4 is capable of drawing approximately 33,000 vectors for a displayable density of 1.3 inches/square inch. The manufacturer informs us that this system may be improved by a factor of two without undue strain or engineering effort so that the slightly improved PDS-4 is capable of approximately 2.6"/square inch.

In Tabular Form	Mag. of 1:1	Mag. of 2:1	Mag. of 4:1
Most vector refresh devices	.4"/inch^2 or less	.8"/inch^2 or less	1.6"/inch^2 or less
IMLAC PDS-4	1.3"/inch^2	2.6"/inch^2	5.2"/inch^2
Improved PDS-4	2.6"/inch^2	5.2"/inch^2	10.4"/inch^2
Other devices	virtually unlimited	virtually unlimited	virtually unlimited

For a high density graphic containing 30"/inch^2, no vector refresh display can completely fill the screen even at 2X. The improved PDS-4 will be capable of full screen displays at 2X when graphic density falls below 21"/inch^2. In percentages of maximal density (30"/inch^2 at 1:1, 7.5"/inch^2 at 2:1, etc.) that is displayed, the devices perform as presented below.

(9) Maximum High Density Area

The values of paragraph (8) above for a feature density of 30"/square inch, translate to the following:

	Display Density Potential		
	Mag. 1:1	Mag. 2:1	Mag. 4:1
Most vector refresh devices	1.33 inch^2	10.7 inch^2	85.3 inch^2
IMLAC PDS-4	4.4 inch^2	35.2 inch^2	full screen
Improved PDS-4	8.8 inch^2	70.4 inch^2	full screen
Other devices	limit of display area ⟶		⟶

(Note: Full screen assumed to be 100 square inches)

	Percentage of Display Area		
	Mag. 1:1	Mag. 2:1	Mag. 4:1
Most vector refresh devices	$\leq$ 1.3%	$\leq$ 10.7%	$\leq$ 85.3%
IMLAC PDS-4	4.4%	35.2%	100%
Improved PDS-4	8.8%	70.4%	100%
Other devices	100%	100%	100%

2. Graphic Digitizers

a. Functional Purpose

- o Entry of graphic coordinate locations for feature actions and interface with graphic display functions.
- o Low volume, relative digitizing of feature lines from any form of graphic (e.g., sketches, maps, photography, etc.).
- o General layout area for compilation materials and graphic plots.

b. Required Characteristics

- o Table Size - 42" (Y axis) x 58" (X axis) digitizing area
- o Basic Resolution - $\approx$ .002"
- o Overall Accuracy - $\approx \pm .005$"
- o Repeatability - $\approx \pm .002$"
- o Cursor - used for point locating/digitizing and trace digitizing; provisions for at least 3 control buttons on cursor.
- o Tilt and height adjustments
- o Table physical characteristics should allow for adding an above table gantry for supporting display device.

A number of good quality, high accuracy digitizing devices are available. A summary of the characteristics of four representative models are presented in Figure III-1. Trade-offs for selecting the graphic digitizer can be based primarily on:

- o Costs of table, options, and interface;
- o Availability of hardware interfaces (compatibility);

	DATAGRID	GRADICON
MANUFACTURER	BENDIX	INSTRONICS
SIZE	42" x 60" 36" x 48"	48" x 60"(62" x 78" Table) 36" x 48"(50" x 66" Table)
RESOLUTION	.001"	.001" or .01 mm
ACCURACY	$\pm$.005"	$\pm$. 004" or $\pm$.1 mm
REPEATABILITY	$\pm$.001"	$\pm$.001
CURSOR TYPE	Free-moving (Various types) 5 buttons with status lights	Free-moving (Various types)
ADJUSTMENTS	Tilt Height	Tilt Height
BACKLIGHTING	Optional	Optional
PRICE	≈ $18,000 Plus special options	≈ $18,000 Plus special options

Figure III-1 Digitizer Characteristics

- Special options available (e.g., cursors, magnifiers, adjustments); and
- Vendor interest/capability to provide special gantry if required for display device.

3. Cursor Control Devices

Interactive graphic input is generally provided through the use of an I/O device which assigns some numeric value to a physical movement. Examples of such devices are graphic tablets, joysticks, and track balls. These devices generate an analog signal in response to the displacement of a sensor. The analog signals are converted to a digital number. In order for the user to ascertain the magnitude of the resultant digital value, a feedback loop is provided by a crosshair displayed on a graphic output device. The equivalent digital position generated by the input device may therefore be tracked by the analog cursor display. Most of these cursor control devices generate digital position information to an accuracy of 1 bit less than an associated display device. If this accuracy is insufficient in the compilation system, simple software techniques can be used to produce display-equivalent accuracy.

The following section discusses four alternative cursor control (graphic input) devices. The light pen and mouse have been eliminated from consideration because of the inability of either of these devices to easily pinpoint a given position on the display screen.

a. Graphic Tablet

The graphic tablet has the advantage of approximating a pencil in its usage which may make it more acceptable for use by a cartographer. It also can be used for course digitizing of a small graphic. Its major drawback is that it is somewhat difficult to specify points within $\pm$ 100 mils. The pencil is awkward to hold in a fixed position while generating an interrupt to indicate the (X, Y) position is to be accepted as a data point.

b. Joystick

The joystick appears to be a somewhat better device for locating points with a high precision. This device consists of a handle which

can be moved to generate an analog signal. The primary reason is that the joystick will hold its position even when the user's hand leaves the device. Thus an independent interrupt (i.e., from another device) can be generated for data acceptance without modifying the position of the cursor. This device, of course, cannot be used for accurate tracing of a hard copy source.

c. Track Ball

The track ball is a ball which can be rotated to generate an analog signal. Like the joystick, interrupts may be generated without movement of the cursor, and the device is also incapable of being used for accurate tracing. The track ball has an advantage which neither the graphic tablet nor the joystick possesses; the track ball is lineally continuous. The track ball can move the cursor off the screen. This feature can allow the user to automatically indicate that he wishes to move the displayed area in the direction of the cursor.

d. Digitizer Cursor

Compilation Station configurations which contain digitizers can use the digitizer cursor to control the display cursor. The hard copy graphic and the graphic display would be registered. The digitizer cursor when placed on a feature on the hard copy graphic would cause the display cursor to be placed in the identical position on the displayed feature.

The use of the digitizer cursor in registration to the CRT screen is an absolute mode of cursor control. A relative mode of cursor control can be provided for operations which are primarily CRT oriented. This can be implemented via assigning a section of the digitizer table to be mapped to the CRT face on a 1 to 1 basis. This relationship would effectively model a graphic tablet and would allow the user the convenience of working in an easily accessed portion of the table without reference to the hard copy graphic.

4. Keyboard/Function Control Devices

It is not necessarily required that the compilation system contain all keyboard items identified below; they are given here to indicate the types available as shelf items, and to show typical functional uses for each

type. Other control devices exist as state-of-art or developmental items; voice recognition devices are notable among these, and are discussed in this subsection.

a. Alphanumeric Keyboard

Associated with the graphic CRT display device it functions as the prime conversational input vehicle. The compiler enters commands, requests, and parameters through this keyboard, covering such functions as:

- o Graphic or alphanumeric display
- o Feature group selection by entering class or geo-descriptive data
- o Feature header modification, and addition
- o Base scaling
- o Display symbology assignment
- o Temporary symbolization assignment
- o Alphanumeric text placement
- o Function selection

No significant trade-offs; the keyboard is logically integrated with the CRT display device, but should be physically mobile. Design considerations include physical placement, orientation, and mobility. The level of language to be used between the compiler and the system deserves significant consideration. Some vendors supply a small group of user-definable special function keys.

b. Special Function Keyboard

A programmable keyboard, usually CRT display vendor supplied, 16-32 buttons. Used for calling and executing specific applications routines usually relative to data manipulations, (and not requiring variable alphanumeric modifiers) such as:

- o Header display
- o Display scaling
- o Display symbology/on or off
- o Feature manipulation
- o Interactive feature generalization functions
- o Feature deletion

Design considerations include use of programmable back-lighting; single, sequential or parallel use of multiple buttons; use of coded overlays to expand the keyboard's functional power, logical button grouping, physical placement, orientation, and mobility. Combining some functions appropriately can reduce the total number of necessary keys.

c. System Control Keyboard

An alphanumeric keyboard and print unit logically associated with the mainframe computer component and the executive or operating system software. It functions as the communication vehicle between the system operator and system operations. It is used to invoke high-level system application tasks and utility routines, and is a point of system entry for program development and some diagnostic operations.

The prime trade-off factor is hard copy vs. CRT display output. The latter offers very high writing speeds, but no permanent record is available unless a separate hard copy device is purchased; this unit produces a hard copy of the screen display in approximately 30 seconds. Hard copy units of the teletypewriter variety are available today with acceptably high writing speeds and reasonably quiet operation. Their costs are competitive.

d. Voice Recognition Devices

Voice recognition systems are seeing increased operational usage. We believe that a voice recognition system is a potential replacement for the alphanumeric and special function keyboard within the compilation system. The VR systems allow the user's voice to be utilized as a digital input. The user establishes a vocabulary at run time which permits an interrupt to be associated with each defined word. The VR's primary use is seen for selecting functions for execution, commands to accept or reject an action, and header encoding. At the present time, however, there has been little information in the literature concerning human factors relative to the use of voice recognition techniques.

The use of VR technology with respect to cartography is currently being investigated by RADC. The results of RADC's experiments

will be evaluated with respect to the compilation activity. If VR techniques are seen to be applicable, they will be incorporated within the compilation system. The system specifications will provide for a VR interface by isolating the alphanumeric and special function input subsystems such that it can be directly replaced by voice recognition inputs without modification to operational software. For example, a special function keyboard (i.e., a keyboard which generates a unique interrupt for each key) or the alphanumeric keyboard could be replaced by a VR unit which would generate a unique interrupt for each word in its vocabulary. The action to be taken by the system as a result of the interrupt would not be altered via use of VR input. This system definition will not be impeded pending the results of the RADC experiments.

5. Alphanumeric Displays

The alphanumeric display will be used as a control device within the compilation station. The requirements for the alphanumeric device are:

- Write time - 1 second
- Detached keyboard
- Large character size
- High contrast
- 20 lines at 60 characters per line

Many alphanumeric terminals meet or exceed the above requirements. The approximate cost of these terminals ranges from 2K to 6K depending upon the data manipulation capabilities of the CRT.

The following options are considered desirable but not required:

- Function keys
- Cursor control in all directions including home and return
- Addressable cursor
- Cursor blinking
- Character insert and delete
- Roll

Each of the above options can be simulated or modeled using software with a less expensive CRT. However, the more sophisticated display has the advantage of requiring less processor servicing and less storage.

The character insert and roll features are particularly desirable for feature header modification. Fields may be modified in the header display by direct insertion. If the header requires multiple pages, the roll feature may be used to easily view all header data.

6. Graphic Plotters

a. Function

The purpose of the graphic plotter is to produce full size interim review plots. The plots would be used to view and analyze compilation results on a medium closer to that of final chart products. It is anticipated that the review plotter will be shared with other compilation stations and/or cartographic systems.

b. Required Characteristics

The compiler would be able to call for plots at least by feature class; hence the plot medium should be transparent for overlay viewing and comparison purposes. Since the plots would be used primarily for review purposes, the plotter must be capable of producing review/proof quality.

c. Plotter Types and Considerations

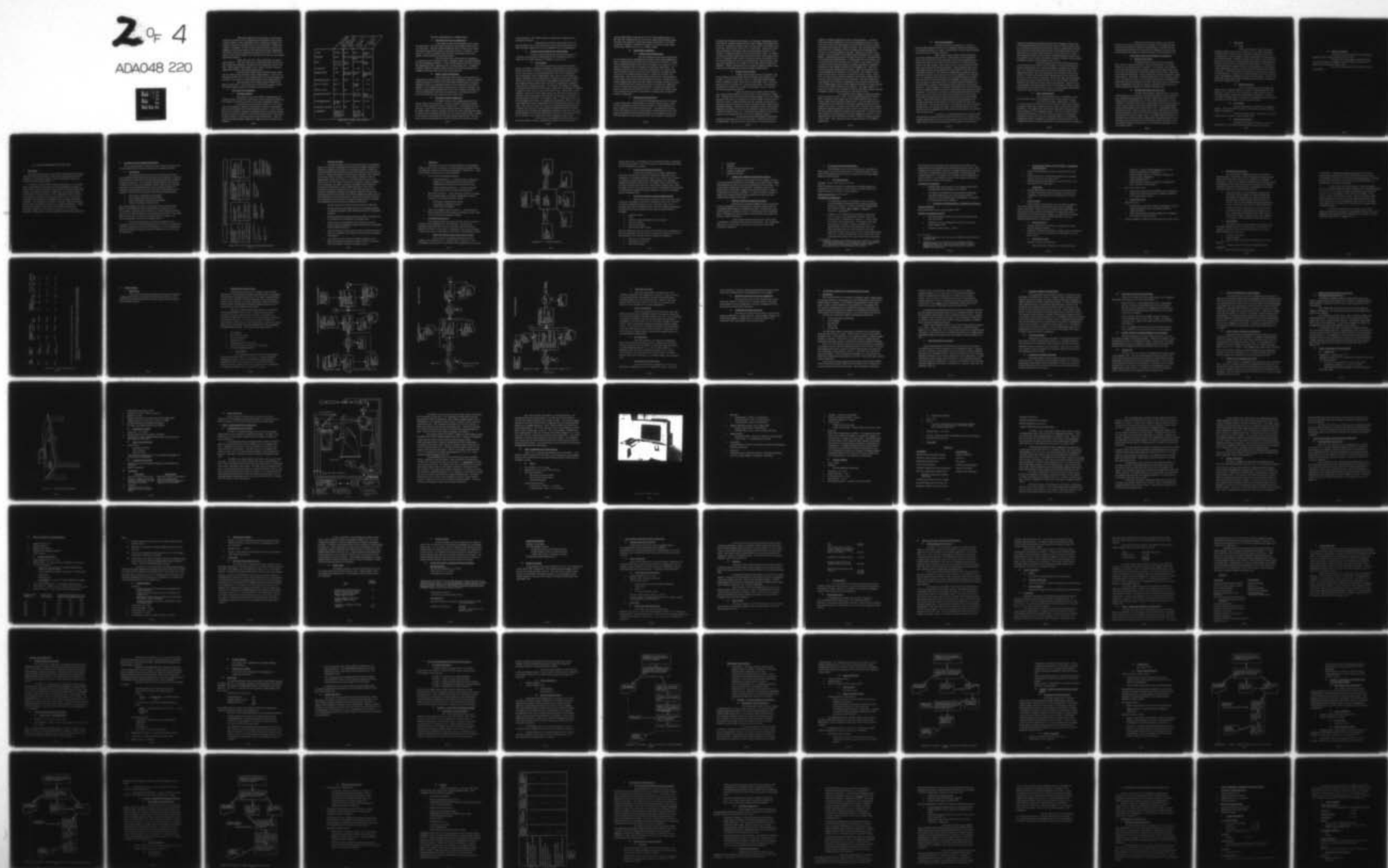
Plotters can be classified within the following major descriptive categories: vector (lineal), raster, contact, and optical/laser.

Vector: features are plotted individually and sequentially. Plotting tools can be of either the contact type (pen or scribe) or the optical/laser type, whereby the light or laser beam draws the features onto a light-sensitive medium.

Raster: elements of all features that lie on a single ordinate line are plotted on a line by line basis. Optical or laser drawing is employed, but electrostatic printing is more commonly used.

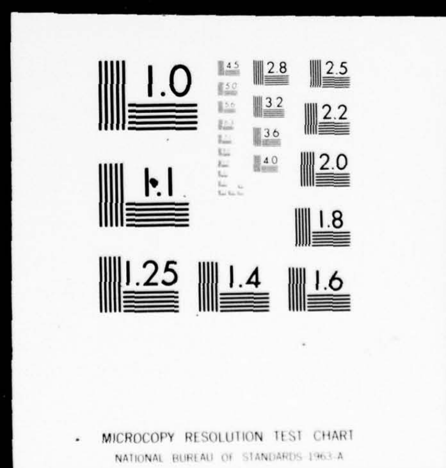
AD-A048 220 PRC INFORMATION SCIENCES CO ROME N Y F/G 8/2
CARTOGRAPHIC COMPILATION STUDY. VOLUME I. SYSTEM REQUIREMENTS A--ETC(U)
OCT 77 M L TAYLOR, R P O'CONNOR F30602-73-C-0036
UNCLASSIFIED RADC-TR-77-340-VOL-1 NL

2 of 4
ADA048 220



2 OF 4

ADA048 220



While there appears to be no problem in achieving all required resolution/accuracy/repeatability specifications with currently available plotters, other capabilities such as complex and multiple symbology in conjunction with high speed are less achievable. Variable line weights, for example, are only crudely and slowly produced on the less expensive vector/contact plotters; total plot time increases significantly with greater amounts of symbology and feature data volume. The advantages of vector/contact plotters are somewhat lower cost and less required applications software.

At the other end of the trade-off spectrum are raster/optical plotters. They offer high speed, constant plot time regardless of data volume and complexity, and spot size and resolution as low as .001 inch. Disadvantages include higher cost, a greater amount of required applications software, and high processing costs.

Numerous other plotter type combinations exist, which will be considered for alternative system configurations. Trade-off considerations include off or on-line configuration, ease of programming and operation, cost, speed, and cartographic quality of the output product.

Characteristics of four different types of plotters are given in Figure III-2. The list does not necessarily show typical values, but indicates types of plotters available as off-the-shelf items.

7. Processors and Peripherals

a. Functional Purpose

The purpose is to provide adequate computational and storage capacity to satisfy the requirements of the compilation station support software and perhaps also those of the data manipulation software.

One of the goals of the system design is to select a processor and peripheral equipment configuration to provide a stand-alone, single thread operation for an initial development effort. Once tested and found to be acceptable, additional compilation station components could be incorporated in such a manner to cost-effectively share some of the initial hardware/software resources provided by the initial system. Only processors permitting flexible expansion to support resource sharing will be examined.

	AUTO-TROL 6000 Series	BROOMALL 2000	CALCOMP 1675	VERSATEC 2160
TYPE	Flatbed	Drum	Film	Electro-static
MEDIUM	Paper	Roll Paper	Microfilm/ fiche	Roll Paper
SIZE	40" x 40" to 54" x 72"	30" x length	16-105 mm	20" x length
ACCURACY	.004	.0025	N/A	1%
RESOLUTION	.0005	400 steps per inch	80 lines/ mm	160 raster points per inch
REPEATABILITY	.001	.0025	N/A	N/A
NO. OF TOOLS	up to 8	1	20 line widths	N/A
TOOL TYPES	Pen	Pen	N/A	N/A
MAXIMUM SPEED	22 in./sec.	5 in./sec.	400,000 incr./sec.	paper moves at .45 in./sec.
PURCHASE PRICE	34,000 to 42,000	11,500	140,000	11,000
MONTHLY RENTAL	2,000 up	485	6,000	N/A
COMMENTS	OEM; mate with any 16-bit mini-computer.		16,384X 16,384 addressable matrix.	

Figure III-2 Plotter Characteristics

Possible configurations are identified below.

(1) Distributed Star-Burst Configuration

In the initial version, the distribution would require two processors. The host would provide the station support group of software functions. The data storage peripherals such as random access disks and magnetic tape drives would be connected to the host. Likewise, a line printer, or system command console terminal and perhaps a hard copy plotter would be located at the host processor.

The other processor would provide the intelligence to control the local environment of the compilation station including primarily the data manipulation software. To this satellite processor would be attached the alphanumeric CRT, digitizing cursor and the graphic CRT. Additional satellite compilation stations would be added to the star-burst network by a multiplexed interface unit to the control host processor.

(2) Single Control Configuration

This configuration would require one processor providing both the station support and graphic data manipulation software functions. Both the processor and its I/O bus would require sufficient power to permit additional clusters of compilation stations to be incorporated as the system expands. Each compilation station would possess no intrinsic intelligence of its own (no processing capability) and would require complete servicing of its CRTs and digitizing cursor by the main processor. The single processor would also control the data storage and hard copy devices.

(3) Distributed Ringed Configuration

The initial version of this configuration would look like the single central processor. However, satellite compilation stations would be locally supported by their own processors. The satellite processor would be a scaled-down version of the initial processor providing some of the station support software functions and all of the data manipulation functions. In addition to the compilation peripherals each satellite would require a random access disk to accommodate the local data storage requirements. The tape drives and hard copy peripherals would be shared by the central processor

and the satellites, all of which would be connected by a ringed data communications network.

Examination of the data requirements of the compilation system such as baud rates, data volumes and response times and other selection criteria will lead to the optimal choice of configuration.

b. Required Characteristics and Considerations

The processing requirements will be discussed here irrespective of the possible configurations for the compilation system in which one or two different types of computers could be used.

(1) Word Length

The 16-bit word found on most modern minicomputers is adequate for display processing, communication and control elements of the system. However, for accurate arithmetic precision required for file conversions and transformations the 16-bit word is insufficient. Most cartographic numeric applications would require at least double-precision computation and its attendant loss of speed on a 16-bit minicomputer. Having a word size of 32 bits found on many popular minicomputers would allow single precision arithmetic for nearly all cartographic computations required by the compilation system. For example, the latitude or longitude of any point on the earth's surface could be expressed in geographic coordinates in units of 1/100's of an arc second in 29 bits or less. Conversely, a 2-mil minimum vector size for data represented in the CRT frame would permit expression of either component of any absolute cartesian pair at 1X within the largest graphic product (38" x 54") within 16 bits. It would appear that a 16-bit word length would suffice for graphic data manipulation, whereas a 32-bit word length would be more appropriate for file transformation in map coordinates. The trade-off in this case would be sacrificing processing speed for a cheaper processor that would perform all compilation software functions. It may also turn out that those applications requiring a 32-bit word size could be best handled in a batch processing mode and hence the loss of speed would have no impact on the response time at the compilation station CRTs.

In the central host multiplexed scheme in which all batch pre-graphic and post compilation processing could be performed, it

would be appropriate to consider the use of a 32-bit midi-processor. In the other two configurations, the 16-bit word length would probably suffice. The price ratio between a 32-bit midi-computer with 16K of core and its 16-bit mini-computer counterpart with 16K of core from the same vendor family runs a little over 2 to 1 (i.e., \$20K to \$10K).

(2) Input/Output Capabilities

(a) Response Time Requirements

The most stringent requirement imposed upon the I/O capacity of the compilation processor(s) is that of transmitting windows of cartographic feature data to the refresh vector CRT device. A goal of the compilation station refresh CRT is to display over a typical 10" x 10" window cartographic data at a density of 20 inches per square inch. Assuming an average vector of 10 mils and a refresh rate of 1/30th of a second, the display processor would have to be capable of refreshing 200,000 vectors every 33 milliseconds to provide a "screen full" of flicker free graphic data. This refresh requirement by itself may be overwhelming for current state-of-the-art refresh CRT display processors. Packing two vectors per display instruction would still require an effective memory cycle time of 330 nanoseconds and a memory size in excess of 100K at the display processor to achieve the desired graphic display. Although this display rate may not be achievable with today's devices, we may use the estimated 200K vector maximum screen full as the basis for assessing other compilation hardware components.

(3) Display File Characteristics

As a discussion starting point because of the volume of data and real-time considerations for realistic response times, assume that the compilation data file has been converted to a corresponding companion display file in a batch processing mode. The display file structure will be grid indexed to allow a pseudo-dynamic windowing effect at the CRT. Display data physically located in grid squares in the neighborhood of a selected viewing area would be preformatted in such a manner to permit fast

retrieval from random access storage. For example, neighboring feature data would be collocated physically on the disk to optimize throughput when accessed. The physical region on disk corresponding to a grid index square on the CRT will be herein referred to as a grid block. Grid blocks will be sparsely populated with display data to permit possible inclusion by the computer of additional display features and symbology strings. In addition to their preformatted display instructions and vectors, each display feature will be accompanied with a feature ID and hierarchical information to permit (1) association with the master compilation file, and (2) provide a data extraction capability for the compiler to select only subsets of data to be displayed. Finally, grid blocks will be arranged on disk in quickly retrievable clusters paralleling their physical display neighborhoods.

(4) Random Access Devices

A stated system response time is to provide a full screen display of normal density (20 inches/square inch) within 10 to 20 seconds. A normal screen full in this case represents 200,000 display vectors residing on a disk, which may be located either locally at the display processor or remotely at a central host processor. The significant parameters to consider are the type of disk storage, mean access time, and data blocking/denstiy factors.

Types of random access devices include moving-head replaceable disk packs, fixed-head disks, and the diskette or "floppy disk." Moving-head removable media disk packs appear to have the greatest advantage with respect to relatively lower cost and higher capacity than the other two devices. Fixed-head disks have the advantage of speed but are limited by capacity at least with respect to the data volumes required by the compilation system. Diskettes have the advantage of greater interchangeability and rock-bottom cost, but are also limited in capacity and severely restricted by data transfer rate. The disk pack unit will serve then as the random access storage media chosen for the compilation system.

The prinicpal elements that influence performance of disk pack operation are head movement time, rotational speed and recording density. Disk packs can be envisioned as a series of concentric

cylinders rotating simultaneously about a common spindle. A movable read-write head is positioned to access one cylindrical surface at a time. As the disk rotates, the information is accessed from the cylinder surface and transferred to/from the computer memory. This model does not represent the actual management of the recording media and moving-head structure, but should simplify the concept. Physically, the disk is comprised of a stack of platters (recording surfaces) rotating about a common spindle. Hypothetical parameters for disk I/O times are: 30 milliseconds for average head positioning time, 25 milliseconds for one revolution, and a steady-state data word transfer rate of 150 KHZ. The number of words recorded on each cylindrical surface (recording, density) is a significant parameter in determining an effective disk throughput rate. Data is recorded in discrete channels known as tracks, which can be thought of as circumscribing the circumference of the cylinder. The cylinder is comprised of many tracks, and data is accessed one track at a time. Therefore, one track may be read per revolution, and an entire cylinder may be read in as many revolutions as there are tracks. Once the moving-head is positioned, the two factors contributing to the steady-rate data transfer rate is rotating speed (25 ms is fairly typical) and number of words recorded on each track (3000 to 4000 words also typical). The typical number of tracks per cylinder is also typically 20, which means that a cylinder capacity is typically 75,000 words and can be read in about $\frac{1}{2}$ second.

For argument's sake, suppose an arbitrary display grid size would be 1 inch x 1 inch. The corresponding grid block size on disk, allowing for 50% occupancy for 2000 vectors packed two per word, would be 2000 words (less than a typical track). We could expect to locate a neighborhood of 25 grid blocks on a single cylindrical surface (25% of a display screen full). An entire screen full could be retrieved from a typical disk pack in approximately $2\frac{1}{2}$ seconds, which would consume $12\frac{1}{2}$ to 25% of the time allotted to fulfill the response time requirement. In terms of disk space utilized for the display file of a large compilation chart (38" x 54") an estimated total of 80-100 cylinders would be occupied by roughly 8 million words of data. This represents a disk occupancy factor of 25 to 50% of a typical disk.

(5) Data Communications

In order to arrive at a decision as to whether to place the disk subsystem locally at the compilation station mini-processor or to position all disks at a central host processor, the data communications between processors must be examined.

With respect to data communications between processors the significant types include: asynchronous, in which individual data words are transferred under program control and accompanied by an external interrupt, or synchronous in which blocks are transferred under control of the data channel, which steals cycles to access memory and signifies end of transfer by external interrupt. Communications lines vary in complexity and their cost is proportional to the number of bits that can be transmitted in parallel. The amount of multiplexing of separate communications lines into the central processor must be a significant cost consideration. For bit parallel data transfers over communications lines of length less than 100 feet, transmission times are negligible. Multiplexing does have an impact on transmission times and depends upon the contention rate between stations trying to simultaneously obtain a path to the central host processor. In this analysis, an arbitrary contention factor will be estimated. There are significant differences between asynchronous and synchronous mode of transfer. Two factors to consider for asynchronous transmission are the time to service the word receive/transmit interrupt and the latency time (mean time to acknowledge interrupt) of each processor and its operating system. Both of these factors depend upon the interrupt facility in each machine and whether the interrupts are vectored and the diversity of interrupt levels. The greater the diversity and vectoring, the more responsive the processor is to external interrupts. Asynchronous transfer time is at least an order of magnitude greater than the synchronous time to transfer the same amount of data.

In general, the important parameters associated with determining I/O transfer capacity include I/O word size (no. of bits of data transferred in parallel over the I/O bus); presence of a direct memory access (DMA) channel which permits bypassing of the computer's main hardware

registers (as opposed to program controlled I/O); maximum I/O data rate, which frequently equals the cycling rate of memory for DMA transfers; number of external interrupt levels and whether they are automatically vectored; non-vectored interrupt differentiation must be determined by the processor with an increase in latency time; maximum I/O bus transfer rate, which would indicate the degree of parallelism of simultaneous DMA channel transfers possible at any one time; the number of device controller slots and small peripheral controller slots available on the I/O bus.

Assuming both processors have DMA channels and a one microsecond cycle time, we could expect a 16-bit word parallel synchronous transmission rate of 200 KC including a contention rate factor of 20%. We would hope for no better than a 20 KC transmission rate in the asynchronous mode. Since the synchronous rate exceeds the disk I/O rate (200 KC to 150 KC), the amount of buffering necessary at the central host processor could be held to a minimum. On the other hand, the asychronous rate which is much slower than the disk I/O rate would require exorbitant amounts of the central processor's memory for buffering. Therefore, any cost advantage of the asynchronous mode over synchronous would be totally outweighed by the excessive memory costs. The synchronous DMA transfer would be the obvious choice over the asynchronous mode.

(6) Other Considerations

The data transmission time for providing a screen full of 200,000 vectors to the display processor would require $\frac{1}{2}$ second.

Of the 10 to 20 seconds response time, a total of 3 seconds would be used to perfrom the necessary I/O under ideal conditions. To actually realize this response time goal, software performance must be considered. The display data retrieved from disk must be concentrated before transmission to the compilation station. The data extraction function could also be performed at the central processor prior to transmission. Contention for disk access by many compilation stations in a multiplexed configuration must be considered (1 to possibly 4 satellite stations). Data management software and operating system overhead must also be considered.

Without hard facts to the contrary, it would seem that the 10 to 20-second response time challenge can be satisfied by state-of-the-art and relatively inexpensive minicomputers. The disk and data communications transfers on an appropriately equipped central processor allowing interleaved DMA block transfers should be able to handle the job.

c. Trade-Offs for Processor/Peripheral Components

(1) Magnetic Tape Drives

No significant trade-offs are obvious regarding type, costs, or speed of operation. One unit would suffice in a minimal system, but two units give more confidence: (a) backup in case of failure of one unit, and (b) second unit available at any time for urgent image saves, or if a save is automatically clocked and initiated by the system. Input data: batch-processed chart files, chart revision data, previously compiled archival, image restore. Output data: compiled product file, review plot files, image save. The number of tracks (7 or 9) will be determined by compatibility requirements with other machines in the ACS, and by data volume requirements. Since no significant trade-offs are obvious, deferrence will be given to the vendor supplying the mainframe to minimize technical risk.

(2) Moving-Head Removable Disk Packs

Possible logical/physical separate units by reason of functional differences; host and/or distributed program storage, product data files, display processing program storage, display files, symbol library. Primary cost considerations are: (a) data volume requirements, and (b) reliability. The latter should not be compromised; it is much more expensive to save a little money on a one-time purchase only to have malfunctioning hardware permanently destroy man-weeks of work. Compatibility with associated processors reduces technical risk; off-the-shelf interface hardware should be available, and be prior use-tested, if processor/disk units are not manufactured or sold by a single vendor. A possibly significant design consideration is the amount of vendor supplied data management software, and the types of file structuring and access methods within the package. Here, the markedly different overhead factors will contribute importantly to system response times.

(3) Processors

(a) Main

Prime consideration is scope and quality of operating software; prices, size, speeds, etc., are highly competitive. Peripherals offered by the vendor compatible with the processor will be a consideration. I/O bus capacity and interrupt facility also distinguishes processing markedly. Possibly more than one computer in the mainstream depends on data volume and task handling requirements. Multiplexed configuration also allows ease of unlimited system expansion. Functions are control/distribution of system tasks and communications, and execution of certain applications programs. Both 16-bit and 32-bit processors will be considered. Although the industry has tended toward the 16-bit as standard for minicomputers, recently 32-bit "midi-processors" have arrived on the scene challenging the capabilities of large scale mainframes. These 32-bit midis offer directly addressable megabyte memory and plenty of options in the $100K - $200K price range.

(b) Display Processor

Almost no trade-offs; must link tightly with display device. Important items are method of communication with host processor, transfer rates, and data volumes. Scope and ease of use of operating software is important to applications development. Functions are control of display device, management of compilation tasks, interactive communication with compiler and with master data files.

(4) Line Printer

Function; print status, exceptions, and statistical reports. Trade-offs include line width, print speed, and print mechanism (impact or impactless).

A wide price range exists. Preference will be given to the processor vendor to reduce technical risk.

(5) System Control Device

Function; system operator requests, commands, and responses. Trade-offs; silent/non-silent, video or hard copy.

(6) Software I/O Device

Functions; software development and maintenance, diagnostic software input, operating software input.

Possible device types; paper tape reader/punch, magnetic tape (industry compatible units already part of system), card reader, other proprietary magnetic tape.

Ease of use during program development is prime consideration.

IV. DESIGN REQUIREMENTS AND ANALYSIS

A. Introduction

This section presents major points of the design analyses performed during the effort and description of the initial configurations which were evaluated. Several points should be made concerning the conduct and presentation of the design analyses.

To provide a sound baseline of design requirements a set of system goals, requirements, and concepts were first established (presented in Section IV-B). Given the fact that certain hardware was not commercially available we defined an "optimal" configuration, from which all other designs could be evaluated against. Five configuration types in addition to the optimal configuration were defined (Section IV-C). The primary distinction in the alternative configurations was the display technology employed. The configurations, initially considered, primarily addressed the interactive compilation processes (i.e., digital compilation). Design analysis and inclusion of the "source assessment" function was separately evaluated and is presented in Section IV-C-4. The final alternative configurations and their evaluations are presented in Section V.

B. Definition of System Design Requirements

This section presents an overview of major design requirements and concepts defined for the Advanced Revision and Compilation System.

1. Environment

The production environment, which the Advanced Revision and Compilation System (ARCS) is conceived to operate within, is expected to evolve with time because of required technology development and implementation timeframes. The envisioned overall production environment, as defined by the Advanced Cartographic System (ACS) concept, basically conforms to current production phases, with automated systems and techniques being implanted where and when process effectiveness can be validated. The ACS concept consists of four major production phases:

- Source Data Acquisition and Processing
- Data Storage, Maintenance and Retrieval
- Source Exploitation and Product Compilation
- Product Finishing and Reproduction

Figure IV-1 illustrates the logical associations of the major production phases and identifies the major activities which are planned to occur in each phase. Identified below each phase is a list of automated systems which are currently operational in the production environment. The system defined in this report is expected to operate within the bounds of the Source Exploitation and Product Compilation Phase.

The Source Exploitation and Product Compilation Phase represents some of the most demanding processes in terms of cartographic expertise, judgement, and man-hour expenditures. Not too surprising is the fact that automated support to product compilation is one of the least developed areas.

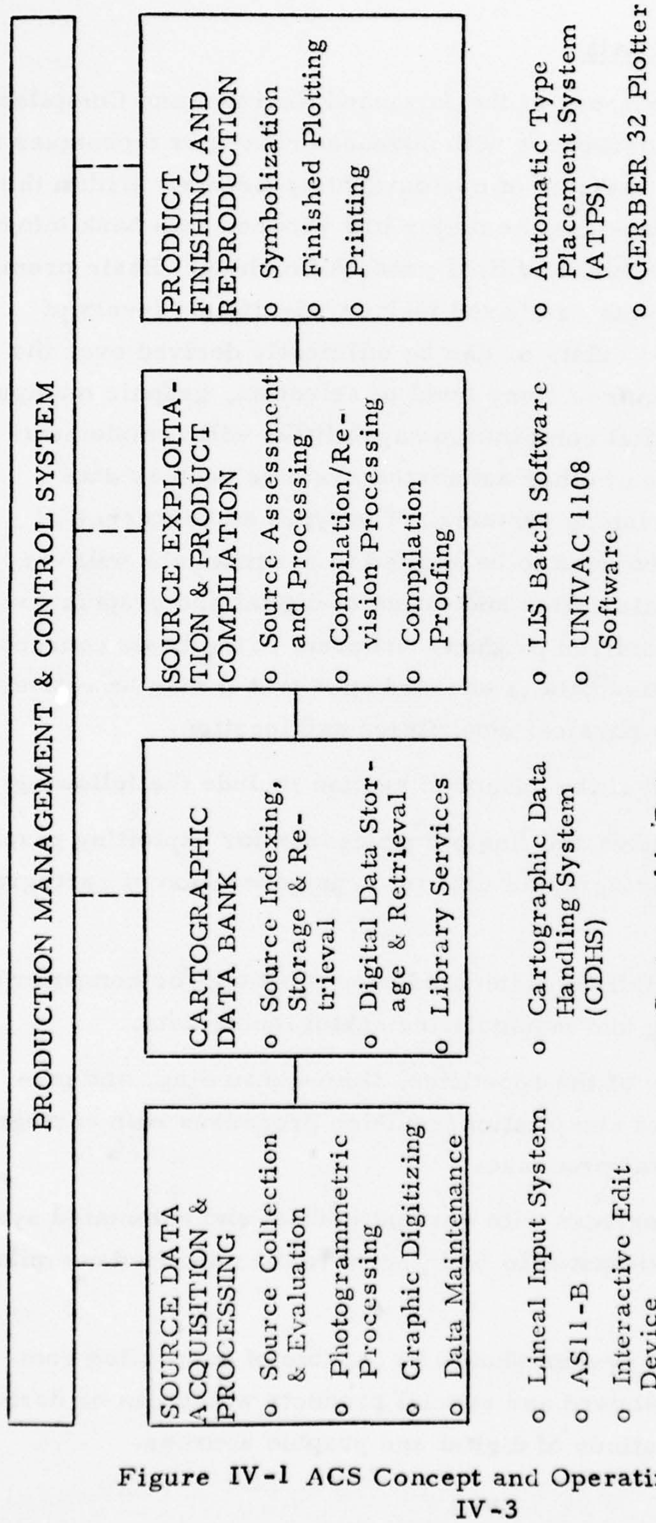


Figure IV-1 ACS Concept and Operating Environment

2. Purpose and Goals

The general purpose of the Advanced Revision and Compilation System is to provide cartographers with advanced computer techniques for effective compilation and revision of cartographic products. Within the ACS environment ARCS provides the major link between data bank information (e.g., digital and graphic) and final product finishing. Basic premises on which the system concepts are based include: significant levels of digital feature information exists or can be efficiently derived over the product area; the data requires some level of selection, graphic manipulation and proofing; and digital compilation capabilities will complement and improve effectiveness of other automated systems such as data banking and automated finishing systems. The types and sequence of advanced compilation techniques to be applied to specific jobs will vary depending upon the characteristics and extent of digital and graphic sources and requirements of the desired product. Inherent in the basic concept is the requirement that feature data is encoded such that it may be retrieved and manipulated based on physical description and location.

Specific goals of the advanced system include the following:

- Provide effective and flexible processes for exploiting graphic and digital cartographic data towards generation of cartographic products.
- Provide specialized automated processes and/or computer aids for displaying and manipulating cartographic data.
- Replace many of the repetitive, time-consuming, and predictive manual compilation/revision processes with cartographer directed digital processes.
- Allow for interfaces with current manual and automated systems which are anticipated to be integral to the advanced compilation environment.
- The advanced system should be capable of supporting compilation of standard and special products which can be derived from combinations of digital and graphic sources.

3. Interfaces

Based on the role of the Advanced Revision and Compilation System and its various components, several interfaces with other manual and automated systems are required as illustrated in Figure IV-2 . Three general types of interfaces are currently defined:

- o Pre and Post-Compilation Interfaces
  - Data Bank Interface - consists of input of digital and graphic source information and associated source identification information and recommended usage.
  - Product Finishing Interface - consists of output of digital feature files and associated proof plots.
- o In-Process Interfaces - those interfaces which occur during the compilation phase and involve supplementary manual techniques or automated systems, such as:
  - production management and control
  - aeronautical compilation services
  - shaded relief compilation
- o Internal Compilation System Interfaces - those interfaces between subsystems of the advanced compilation system which are addressed in the following sections.

4. Functional Requirements

This section presents the major functions which the Advanced Revision and Compilation System must perform. The functional capabilities presented below are not necessarily directed at specific software, hardware, or procedures. Delineation of the design strategies to achieve the required capabilities are presented in the following sections.

a. Digital and Graphic Source Assessment Function

Given a product compilation assignment and best available source materials (e.g., digital, graphic, textual, etc.) the cartographer must perform an assessment of the applicability and common-

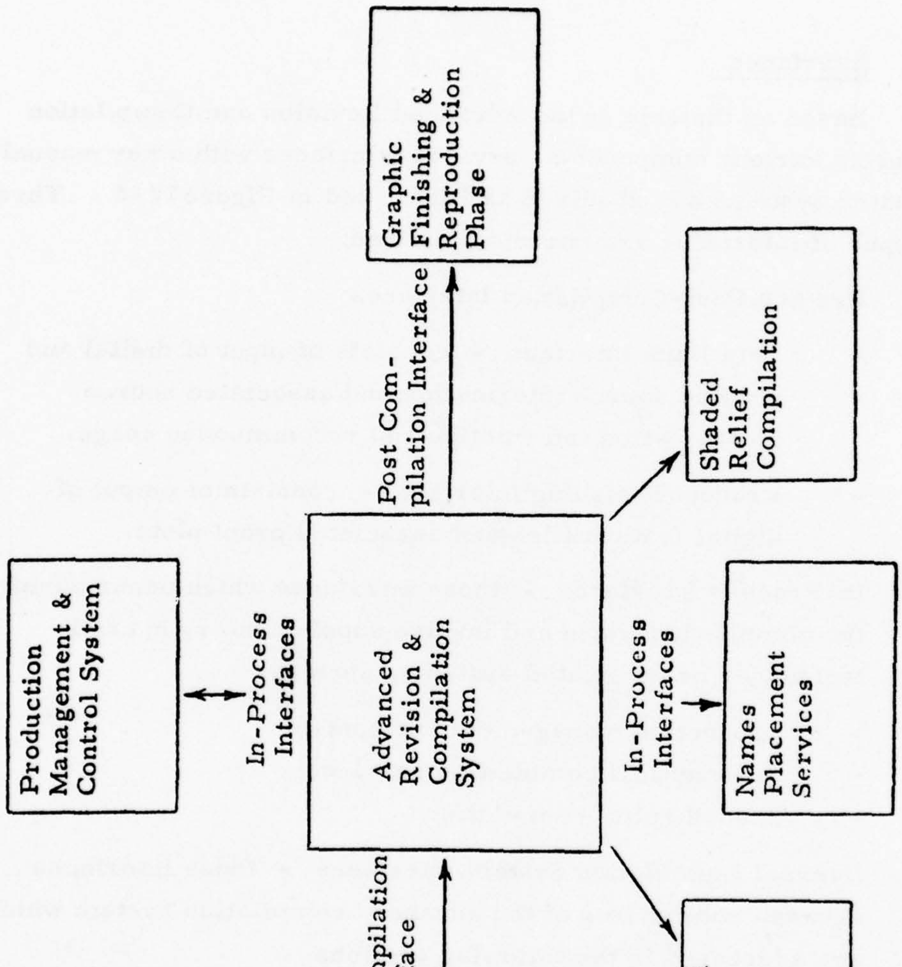


Figure IV-2 System Interfaces

ality of each source. The purpose of the assessment function is therefore to determine the utility of each source prior to detailed feature data extraction or manipulation processing.

b. Feature Data Extraction Function

Feature data extraction (i.e., graphic digitizing) is expected to be performed at either an interactive compilation system component or a dedicated digitizing system (e.g., lineal, raster scanner, or automatic line following system). Determination of the digitizing approach will depend on efficiencies of available systems and the extent and type of the data extraction task. Minor feature modifications, based on graphic sources for revision types of jobs are anticipated to be performed at an interactive compilation station, with direct creation of an updated product compilation file.

c. Feature Data Merging and Formatting Function

This functional area consists of a set of processes which enable the cartographer to assemble cartographic feature data sets into a common compilation reference frame. The source data sets are extracted from data bank holdings and/or derived by digitizing techniques. The data sets normally represent a wide range of format diversity, including:

- o projection system
- o scale
- o coordinate type (geographic table rectangular)
- o area of coverage
- o data point resolution
- o feature information content

Given the feature data sets and each of their attributes the cartographer can direct the application of proper types and sequence of software processes. The minimum set of software processes includes the following:

- o Projection Transformations
- o Registration and Scaling
- o Line Generalization

- Sectioning
- Paneling
- Feature Extraction/Suppression
- Feature Symbolization
- Digital Rectification

d. Graphic Data Display and Interactive Function

The purpose of this function will be to display selective feature information such that the cartographer can evaluate feature content and positioning and execute necessary compilation/revision actions. Due to the volume of information and extensive compilation actions to be performed the man/machine rappore and associated design is critical to development of an effective capability. To allow for product revision or update, this function will also include provisions for data entry from supplementary graphic information.

e. Plotting, Proofing and Reporting Function

Inherent to the overall compilation phase are provisions for the cartographer or review personnel to perform various levels of verification and proofing of compilation processes. Performance of the proofing function is expected to occur at various steps in the compilation phase. Plotting will consist of quality review/edit plots and quick proof plots for content verification.

A major human factors attribute of the system will be comprehensive reporting of processes and file contents. The cartographer will receive or can request various process reports at critical steps during the compilation.

5. Accuracy/Tolerance Requirements

The following accuracy and requirements for compilation of DMA products have been extracted from: 1) JOG Specification, 2) Navigation and Planning Charts Standards and Tolerances, and 3) the DMAAC Quality Control Standards.

a. JOG Specifications

Accuracy - Series 1501 and Series 1501 Air

90% of all planimetric features, except those unavoidably displaced by exaggerated size of symbols, be located within .02 inches of their geographical position as referred to map projection.

Maximum Trim Size 22.0" x 29.0"

Compilation Symbolization[1]

- o For delineating symbols in compilation, strict adherence to the lineweights represented by the symbols specifications shall not be required. It shall be sufficient to approximate line weights by using a fine, medium, or heavy line, whichever is appropriate.

- o Symbols may be approximated providing the modification does not create a color registration problem, distort the correct shape or orientation of a feature, or create a doubt as to what a symbol represents. For example: the length and spacing of crossties in railroad symbols may be approximated, but the lines representing the tracks must hold the positions that are to be maintained on the color separation drawing; the diameter of circles symbolizing springs, wells, etc., may be approximated, but the center of the circle must mark the location of the center of the feature; the lengths

1. Only three different line weights (colors) are required for centerline compilation symbolization. All symbolization may be approximated (i.e., specialized symbolization for display purposes); only positional locations, not representation are critical.

of the dashes and spaces between the dots of drainage symbols may be approximated but the alignment of the drainage line must be exact. These examples are not intended to comprise a complete listing but are indicative of the types of modifications that are permissible. In delineating any modified symbol for a spot feature, the compiler must be careful that its center, insofar as is practicable, marks the true location of the center of the feature as it exists on the ground.

Lettering on Compilation[2]

- o Labeling which will not appear on the published JOG shall be distinguishable from that which is to be shown.
- o Descriptive and explanatory notes pertaining to topography and culture appearing on the source material shall be retained on the compilation when symbolization is inadequate to properly portray the conditions.

b. Navigation and Planning Charts - Standards & Tolerances

Accuracy of Detail

90% of all features must be accurate within .010"

Pull-Ups and Additional Source[3]

- o When generalizing, distortion at scale of end product shall not exceed .020"
- o Positional accuracy of alignment of source at chart scale shall be within .020"
- o Freehand transfer limits, $\pm$ .020"

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2. A special type style, color, or type size should be reserved for the annotation file.

3. Alignment of any new source data to the display file will be a potential problem area. Reference points common to both the display file and the new source will be required for control to position new feature data.

c. Quality Control Defect Guide TPC/ONC - Compilation Source/Overlays

- o Control point displacement must not exceed .005'' at chart scale.
- o Features other than control points displaced or misaligned must not exceed .01'' at chart scale.
- o Displacement of parallel features, to allow clearance, must not exceed .02'' at chart scale.

Manuscript

- o Detail displaced from control points must not exceed .005''.
- o Transfer of detail from source material or control base to compilation manuscript must not be displaced in excess of .010''.

6. Human Factors

Product quality and production rates are affected greatly by the overall rapport between the human operator and the compilation system components. Numerous factors constitute this relationship, and any one factor whose quality is unacceptable can degrade the overall performance of the human/machine alliance. The team plans to consider all of these human factors, which are delineated below, to achieve optimum operator/system collaboration.

a. Physical Factors

- o Working environment; temperature, humidity, noise level, ambient lighting conditions.
- o Equipment components; reliability, quantity, physical orientation and ease of use, ease of maintenance, reliability of primary power source.

b. Operational Factors

- o Operator/system communications:
  - input components; alphanumeric and special function

keyboards, tracing/tracking/digitizing tools, source graphics registration and comparison.

- input operations; queries, commands, identifying, locating, graphic manipulation.
- conversational language
- output operations; queries, directives, symbology display, projection overlay display.

o Ease of job restart after:

- normal work interrupt; data reloading, job re-initializing.
- abnormal interrupt; power failure, equipment problems, use of backup binary dumps.

c. Functional Factors

o Response Times:

- human/system; interactive queries, commands, directives, display presentation, data manipulation feedback, report generation.
- batch and preparation; filtering, display list compilation, file merging, report generation.

o System capability to diagnose and report data and system errors.

7. Operating Characteristics

The Cartographic Compilation System must provide an extensive and, in some cases, a fairly complex set of data processing tools, all of which will be directed and controlled by cartographic personnel. To allow cartographers to efficiently and accurately exercise all capabilities, the system must provide the framework and dialogue requisite for effective communication in a cartographic environment. The system will have two basic operating modes:

- o Batch Processing - the user determines the full set of processes required, defines his input and output files, and submits the appropriate job control directives for job execution, and subsequently returns to review the job run. Each job must report all processes performed, errors encountered, and summary of file(s) generated.
- o On-Line Interactive Processing - the man and machine essentially perform complementary processes in real time. Important characteristics of the online mode are man-machine rapport, response times, error detection and diagnosis, and checkpoint and restart procedures.

8. Data Volumes

The amount of data to be processed by components of the Compilation System depends on several factors, some of which are unknown at this time, and which will vary with time. The major factors affecting data volume are:

- o format size of product
- o scale of product
- o density of feature information derived from the master data base
- o average number of data points representing feature alignments
- o point or increment storage formats

For purposes of establishing approximate storage and processing requirements, estimates for number of lineal inches and data points are presented in Figure IV-3 for three major graphic products. The high density ONC would require storage space for 52,500 lineal inches or approximately 13.2 million data points.

Assuming that large format graphics could be segmented into four compilation files, the maximum graphic size is then approximately 18.5" x 26.5", the maximum number of data points to be maintained/accessed for one compilation activity would be 3.3 million, and the number of lineal inches would be 13,125. Further assuming a quality graphic display of at least 9.25" x 8.84" infers that the station data base would require at least 6 displays for 100% coverage. One-sixth of the station data base would be 2170 lineal inches, or approximately 550,000 data points.

Note that the above figures are based on final product density and lineal inch estimates. Assuming that the query of the master digital data base resulted in 150% average of feature content, the above estimates should then be multiplied by 1.5.

PRODUCT	FORMAT SIZE	AVERAGE LINEAL INCHES			DENSITY (Features/In.^{2})			DATA PTS.* (Million)		
		Low	Med.	High	Low	Med.	High	Low	Med.	High
JOG	18 x 26 (468 Sq. In.)	4,000	6,000	10,000	8.5	12.8	21.4	1.0	1.5	2.5
TPC	36 x 52 (1872 Sq. In.)	6,600	16,800	40,600	3.5	9.0	21.7	1.7	4.2	10.2
ONC	37 x 53 (1961 Sq. In.)	6,300	13,800	52,500	3.2	7.0	26.8	1.6	3.5	13.2

Note: Above figures are based on Lineal Analysis Study, August 1966.

* Based on an average resolution of 250 points per inch overall, considering that variable resolutions will be present and feature line definition will be defined by trace and point-point modes.

Figure IV-3 Data Volume Estimates

C. Design Analysis

1. Introduction

This section presents the operational concept and preliminary configurations which were considered for the advanced system. Also presented is the design analysis for inclusion of the source assessment/ data extraction function.

2. Operational Concept and Flow

The Advanced Revision and Compilation System (ARCS) will provide a set of hardware/software/procedure tools to be exploited and directed by cartographic personnel. The system components rely on the user for direction of function assignment and processing parameters. Once directed, the system will perform automatic processes where feasible, and provide the necessary dialogue with the user to assure accuracy and completion of processes.

The types of jobs which ARCS can support are anticipated to vary significantly in terms of size, complexity, and priority. Therefore, the user's approach to performing each job will vary, and likewise exploitation of the advanced system will differ in sequence and duration of processes. Presented below (Figure IV-4) is an operational flow which depicts major process steps, sequences, decision points, inputs and outputs which are anticipated for most conventional compilation/revision jobs. The major process steps include:

- o Job Planning
- o Data Bank Accessing
- o Source Assessment
- o Data Extraction
- o Compilation Batch Processing
- o Interactive Graphic Revision and Compilation
- o Product Proofing and Review

a. Job Planning

The job planning step will consist of all preliminary processes associated with the computation or revision assignment, scheduling, production control, and production strategy planning. Typically, the user will identify the types and characteristics of source materials available for the job. A plan for source exploitation and equipment utilization would normally be prepared.

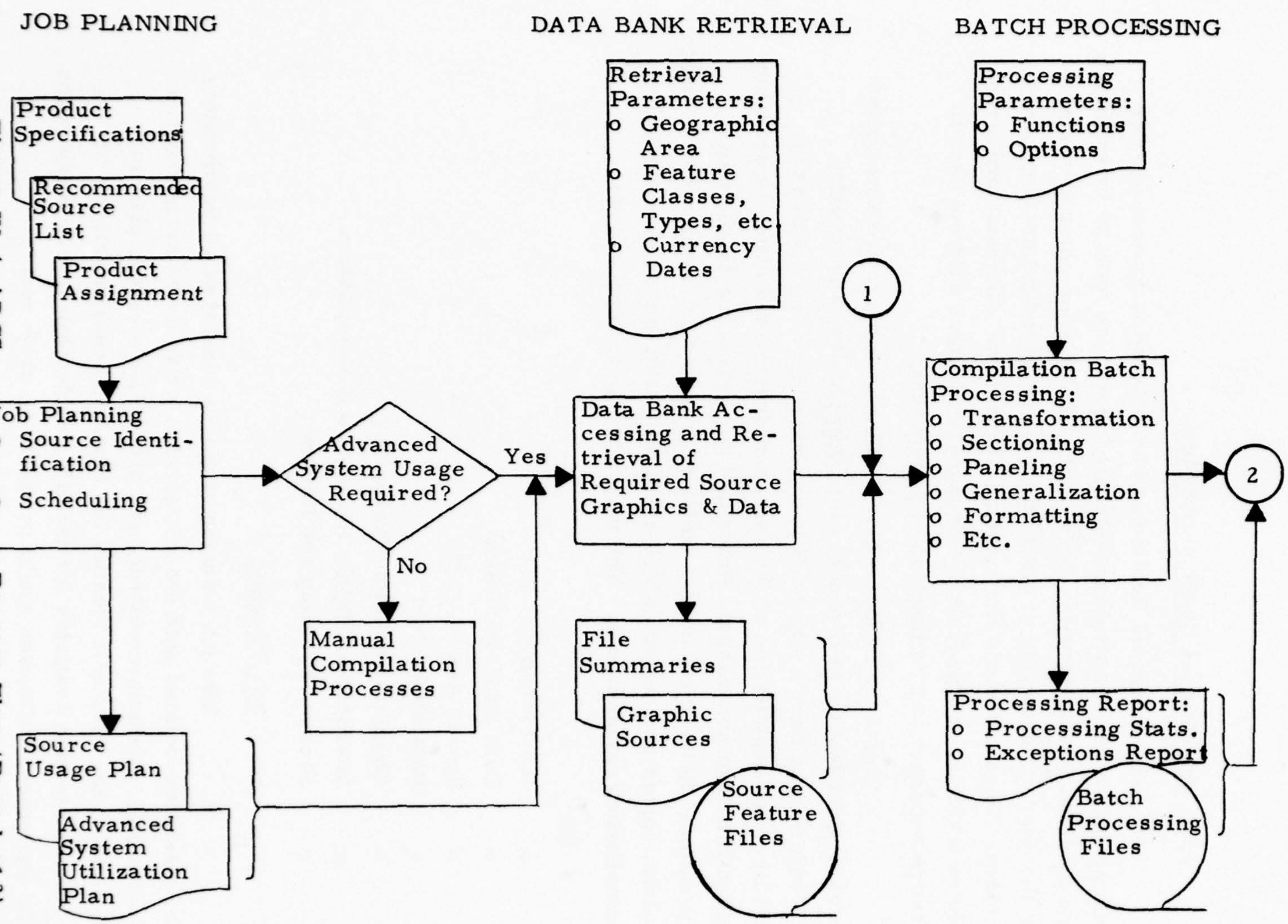

Figure IV-4 ARCS Process Flow (Page 1 of 3)

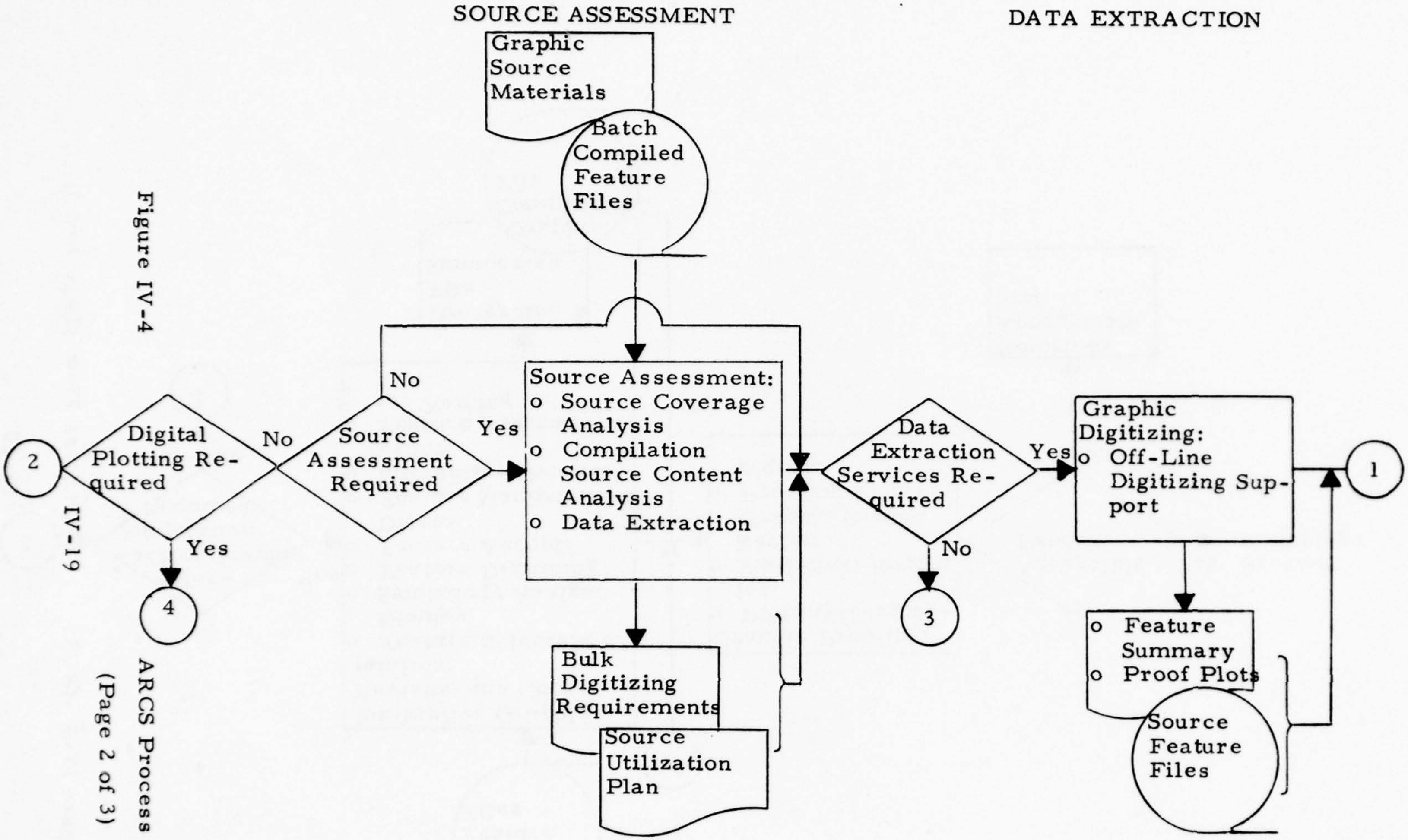

Figure IV-4 ARCS Process Flow

(Page 2 of 3)

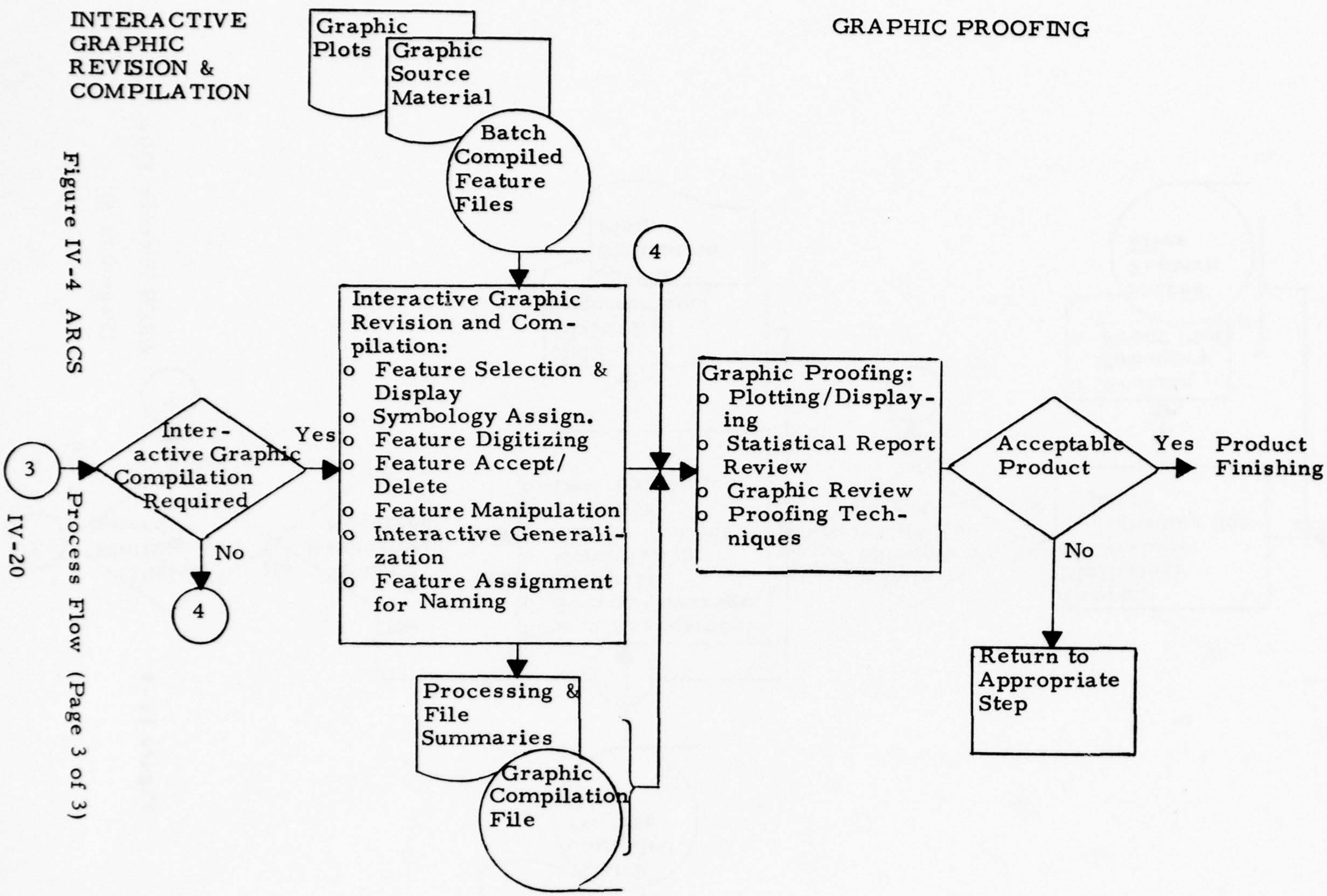

Figure IV-4 ARCS Process Flow (Page 3 of 3)

b. Data Bank Accessing

This step would consist of retrieving all source materials required for the compilation/revision job. Types of sources includes maps/charts, photography, geodetic control information, and supplementary documents and materials. Typically, the cartographer will review source indexes and references to insure completeness and to identify source retrieval parameters.

c. Source Assessment

This step represents the first actual use of the capabilities of the advanced compilation system. The purpose of this step is to assess the utility and contents of graphic sources. The cartographer can define the reference frame for the assessment and subsequent compilation, load and evaluate the exact coverage of digital and graphic sources, and/or compositely display and manipulate multiple graphic source. The results of these activities will result in the determination of exactly which and how sources will be exploited. Additionally, the user can trace or digitize updates to previously compiled graphics for subsequent digital manipulation.

d. Data Extraction

This step consists of description and digitizing of feature information from graphic sources. Digitizing is anticipated to be performed at one of the stations at interactive subsystem and/or at off-line digitizing systems (e.g., LIS, CALMA, RAPS, etc.,). Digitizing at the interactive subsystem is planned to be a common service which can be used in block time periods and/or intermixed with other interactive functions (e.g., editing, display, generalization, etc.).

e. Compilation Batch Processing

This step will consist of applying a selected set of batch type cartographic processes to digital feature files. This step

may be invoked as required, although will typically be performed after data bank accessing and after bulk digitizing of source graphics.

f. Interactive Graphic Revision and Compilation

This step represents the heart of interactive compilation and revision. Activities such as graphic display, interactive generalization, feature manipulation, and names assignments will be performed at the interactive subsystem.

g. Compilation Proofing and Review

This step will consist of all activities concerned with product verification, or support thereof. Special graphic displays (e.g., before/after displays), graphic plots, and process reports can be benerated for the cartographer and review personnel.

3. Preliminary Configurations Considered and Trade-Offs

a. Introduction

This section presents six alternative compilation station configurations. The primary differences represented by these configurations center about the graphic display technology. Each display technology offers certain advantages, but also contains limitations when applied to the compilation task. The resultant configurations have attempted to exploit the advantages of a particular display technology and minimize its limitations while providing various mixes of development time frame, cost, and technical risk factors.

The five basic interactive display technologies presented are:

- o Advanced Graphic Technologies
- o Laser Display
- o Refresh CRT
- o Video CRT
- o Storage CRT

The interactive plotter technology was eliminated from consideration primarily due to its lack of speed. Plotter devices, such as represented by the RADC CDP, are not optimal for use in applications where constant graphic feedback is required. These devices are better suited to editing functions during data base input activities, rather than to product compilation functions.

The use of color CRT's has not been directly presented as an alternative. The primary reason is that the minimum spot size is 15 to 25 mils. The heavy line weight would require excessive scaling to obtain proper line separation for cartographic decision making. However, color CRT's are expected to improve in quality. It will be possible to integrate a color CRT into the refresh CRT configuration when improved color CRT's can provide higher quality lines and spot size.

It has become evident during the analysis phase of the design analysis that no off-the-shelf graphic display device will fully meet the requirement to provide high speed interactive graphics while maintaining cartographic

precision at 1X. Unfortunately, either speed, accuracy, display capacity, display area, or scale must be sacrificed to perform high quality cartographic data manipulation on existing current display devices. Our review of current state-of-the-art and technology projections indicates, however, that display technology, properly directed, could provide a near optimal graphic compilation station within a time frame of 3 to 5 years, based upon discussions with vendors.

The alternative configurations presented below are intended to provide the basic design concepts and structures for a compilation station. They are not presented as rigid designs in that, peripherals may be added or changed or equipment may be arranged differently. These alternative configurations do, however, represent the basic viable technologies available for solution of the automated compilation problem.

Inputs to the Compilation Station could include various graphic mediums (e.g., maps, charts, plots, sketches, photography, previously rectified imagery, etc.), digital files, and various textual documents for supplementary information. The purpose of the non-digital information is for supplementing/updating/verifying of the digital feature information towards producing a product.

b. Interactive System Operations

This section discusses the functions and general mode of operations to be performed at various components of the compilation system. Analysis has been conducted on methodologies for performing the various compilation functions at the compilation system. While some differences exist concerning functional utilization of the various components of each configuration, certain similarities and generalities exist and therefore can be presented separate from any particular configuration. Exceptions and deviations to the following functional application discussion are discussed, as required, within each configuration write-up.

(1) Graphic to Digital File Registration

The graphic table would provide the basis for data entry of supplementary or updated feature lines, mounting of master composite and/or selected feature group plots, and entry of point location data for graphic to digital registration or feature modification actions. A master graticule plot with registration marks, and possibly registration pins, should be first positioned on the graphic table thus providing a basis for effective registration of other selected plots and feature overalys. This technique would provide a convenient method for bringing updated feature plots to the station. The "portable registration pin" technique would permit the digitizer table to accommodate various product format sizes. The digitizer table and associated cursor device would be used for defining areas to be displayed on the graphic CRT and identifying points for locating features for various compilation processes such as deletion, re-alignment, header display, etc. The digitizer cursor would be used in two modes: (1) for locating points/features on the graphic plot, and (2) for control of the cursor on the graphic CRT display for point location and feature manipulation.

(2) File Summarization

Subsequent to file input processing, a file summary in terms of data volume, feature categorization, density, etc., should be printed on the line printer for verification of input (compared with batch processing statistical reports) and general user information. The user at the station can at anytime request a detailed file summary be printed or feature summary displayed at the A/N CRT.

(3) Assignment of Display Symbology

All graphic displays can be presented in line center mode or symbolized mode. A library of standard display symbols for each feature group (uniquely symbolized) will be maintained. The user can review the standard symbology at the A/N CRT and modify the symbol specifications for his particular job, if he desires.

(4) Area/Source/Feature Group Selection

The user will define what feature information is to be displayed. Three types of parameters will direct each display:

- o Source Reference - since supplementary files, representing features derived from different sources can be maintained, the user can select features to be displayed based on file code. The A/N CRT will identify source files which can be selected by the user for display.
- o Feature Group - the user can display all feature groups or selected subsets based on class, type, subtype, descriptors, or special flags. Again, this control will be via the A/N CRT and keyboard.
- o Area - the digitizer table and cursor will be employed by the user to define the area (sub-area) center of the next display.

(5) Graphic Display and Augment/Suppress Current Display

Following definition of the above display parameters, the user can request a display on the graphic display. A button on the digitizer cursor will probably be used for requesting the display. Subsequent to the display being presented the user can augment or suppress feature information over the same area by defining such feature parameters on the A/N CRT.

(6) Feature Add

The user can add new features by digitizing from graphics placed on the digitizer table. The user would define the feature add mode, enter via the A/N keyboard the desired level of feature classification/description information, and digitize the feature location information. Added features can be logically merged with an existing file or referenced to a new supplementary source file. Where a set of features is being digitized from a supplementary graphic which is at a different scale than the compilation scale, a scale factor must be applied to the created point data.

(7) Feature Manipulation and Generalization

The graphic CRT will be used in a highly interactive manner to support the user in performing feature manipulation and generalization actions. The user will define the command via the function keyboard and identify necessary location data via the table cursor device for feature and/or point finding. The graphic CRT while displaying the area and features of interest will also display edit segments (before and after), and unless the action is rejected by the user the original line segment will be erased. A procedural technique, concerning "acceptance or rejection" of activities, should be addressed for consideration. The approach being considered for interactive functions is that, by definition, all actions performed by the user, unless procedurally incorrect (i.e., detected by the system), are assumed to be accepted by the user unless the reject key is depressed. Therefore, progression to successive steps by the user automatically assumes the previous step to be acceptable.

(8) Feature Header Display and Modification

Many of the feature manipulation and generalization processes require the user to locate specific features. To support verification that the correct digital feature was located by the system the header of the located feature will be displayed on the A/N CRT. It's anticipated that, in addition to the header display, the graphic CRT will "blink" the located feature line for 2 or 3 seconds. Since supplementary information is available to the user the feature header may require updating, such as population, number of road lanes, abandoned, etc. The user will define the header field and replacement information via the A/N keyboard and CRT.

(9) Alphanumeric Assignment/Placement

Feature names are anticipated to be included on some compilation files. The user can display on names or compositely with feature lines. A special feature flag is planned which will allow the user to identify a feature for names assignment, placement, and subsequent plots for geographic names specialist. A plot orientation field will be provided to allow the user to assign compilation plot parameters.

c. Optimal Compilation Station Configuration

(1) Distinguishing Characteristics

The Optimal Compilation Station Configuration is based upon system requirements and goals defined for the advanced compilation station and is intended to represent a system which is totally responsive to those requirements.

The configuration described herein would require significant hardware development. The expected performance of the resulting system would be near optimal.

All compilation activities will be centered about the graphic CRT experimental model. Command and control will be provided via an alpha-numeric CRT and a variable function keyboard. The primary graphic input device will be a tracking pencil. A cursor with magnifier can replace the tracking pencil when high quality graphic input is required.

The graphic device would be positioned such that the display face is flush to the tiltable table top. An alphanumeric CRT would be placed at the rear of the table at an angle such that the operator could easily glance up at the CRT face. The alphanumeric function control keyboard should be detached so that it could be positioned in a manner for convenient operation. Variable function keys should be positioned such that they can be operated with one hand while the Track Pencil is used with the other hand. See Figure IV-5.

(2) Major Components and Characteristics

(a) Graphic CRT

- Display area - minimum 20" x 30"
- Brightness greater than 25 ft. lamberts and contrast of 88 to 94%.
- Line Characteristics
  - All chart colors (minimum red, blue, green, black)
  - Variable line widths (4, 6, 8, 10, 12, 16 mils)
  - Symbolized Lines (final symbology, hardware generated)
- Color Area Tints

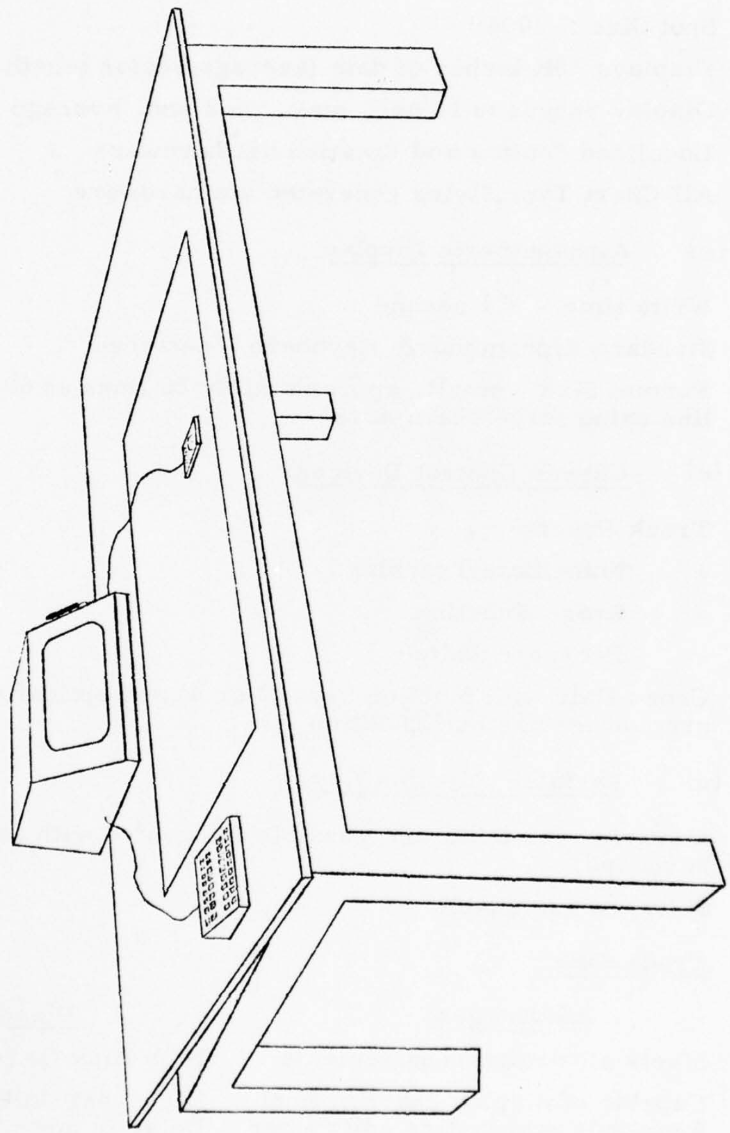

Figure IV-5 Optimal Interactive Station

- Addressable Resolution $\leq$ .001"
- Vector Size $\leq$ .004" (.002" for closure)
- Spot Size $\leq$ .004"
- Displays 18K inches of data (average vector length .004")
- Display Speeds $\approx$ 10 sec. max., $\approx$ 2 sec. average
- Localized Scaling and Rotation via hardware
- All Chart Type Styles generated via hardware

(b) Alphanumeric Display

- Write time - < 1 second
- Standard Alphanumeric Keyboard - detached
- Format Size - small, approximately 20 lines at 60 characters/line using large characters

(c) Cursor Control Devices

- Track Pencil
  - Immediate Tracking
  - Erase Function
  - Pressure Switch
- Cross Hair with function keys (3 or 4) and optical magnifier for precise feature manipulation

(d) Variable Function Keys

- Movable over table top (possibly integrated with alphanumeric keyboard)
- Software assignable

(3) Trade-Offs

Advantages	Disadvantages
o Meets all design requirements	High Risk (hardware development)
o Capable of display chart in final form thus eliminating edits after symbology and plotting	High Cost (Initial Model) Delay in operational deployment Display device unavailable
o Longevity	
o Minimum hardware devices required to perform required tasks.	

(4) System Operations

Since the optimal configuration is assumed to be totally responsive to all compilation station requirements, all system operations would be performed at this station without procedural modifications.

d. HRD-1 Compilation Station Configuration

(1) Distinguishing Characteristics

The HRD-1 Compilation Station uses a large format graphic display device as the nucleus for compilation activities. The HRD-1 configuration will use the graphic display device to continually monitor the entire graphic file.

The compilation station configuration will consist of an HRD-1, (which is a high precision laser driven display device), an alphanumeric CRT, a digitizer which will also serve as a platform for the CRT, and a work area for the cartographer. The HRD-1 has a self-contained track ball for cursor control, a variable function keyboard, and an alphanumeric keyboard. Therefore, these devices are not required as additional equipment.

The HRD-1 is a unique display device and as such requires some discussion. The HRD-1 is an off-the-shelf laser driven graphic display device. Figure IV-6 presents a basic schematic which illustrates the relationship of the major components of the system. The HRD-1 has two projection systems: 1) the storage projection system is represented by lines A and A', and 2) the refresh projection system shown by B and B'. It is important that the relationship between these two systems be understood since much of the ensuing discussion of operational procedures to be used by the HRD-1 configuration will be based on that relationship.

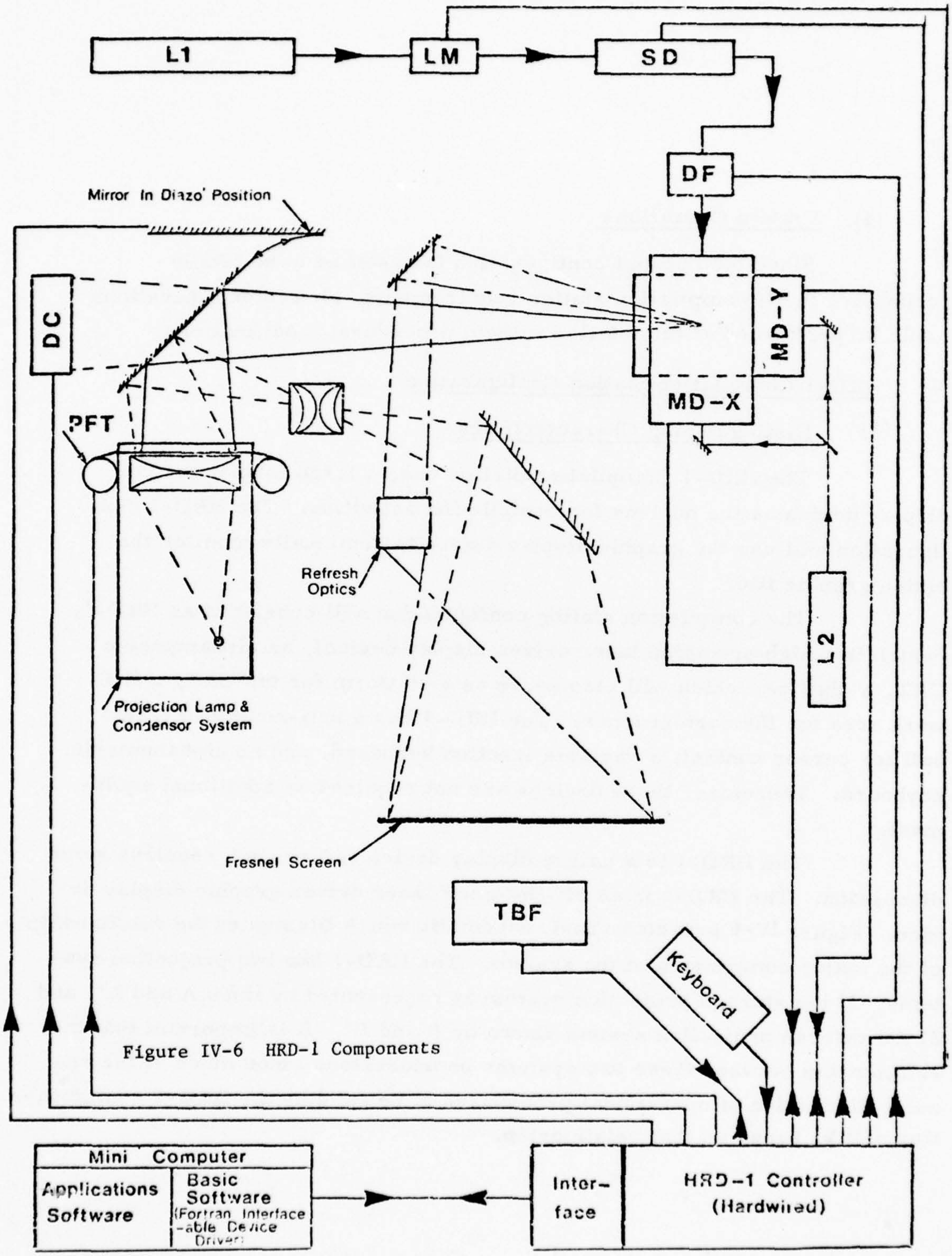

Figure IV-6 HRD-1 Components

DC	Diazo Cassette	LM	Light Modulator	TBF	Tracker Ball & Function Buttons
DF	Dynamic Focus	MD-X	Main Deflector (X)	PFT	Photochromic Film Transport
L1	Main Laser	MD-Y	Main Deflector (Y)		
L2	Auxiliary Laser	SD	Secondary Deflector		

An analogy can be drawn between the storage system of the HRD-1 and the standard storage CRT. It is impossible to modify data which has been displayed without replotting the entire display; plotting speeds are also relatively slow as compared to refresh CRT's. However, here is where all similarities cease. The resolution of the HRD-1 is less than 1 micron, a factor of 100 times better than the best storage tubes. The HRD-1 spot size of less than 20 microns is less than 1/20 the size of a typical storage tube spot. These are but two of the major advantages of the HRD-1.

The storage system of the HRD-1 requires an intermediate storage of graphic data on laser sensitive photochromic film. The film is suspended between the two reels of the photochromic film transport (PFN). After the graphic data is written on the photochromic film along lines A, the image is projected at 10X through two systems of lenses along lines A' to the Fresnel viewing screen. Note that the data actually viewed is a 10X image of the data on the film plane. The size of the film is approximately 2.5" x 4.0" making the view plane approximately 25" x 40", i.e., large enough to display an <u>entire</u> JOG at 1X.

The photochromic film is non-storing and must be rewritten every 15 minutes to retain the image. This rewrite time would allow for 90,000 inches of 8-mil vector data to be written, i.e., <u>nine times</u> the density of an average JOG chart. The photochromic film is reusable, but is unerasable under program control. The image is erased as a function of time if not refreshed. The photochromic film is contained in a reel which is loaded into a program controlled transport. Thus, displays are updated by advancing the film to an unused segment and rewriting the updated data. Previously exposed film may be retrieved and additions made to the original display, however, software must be used to register the additional data. The stored mode data is displayed in black with an orange background.

The refresh system of the HRD-1 is extremely limited. Our calculations show only approximately .5" of data can be drawn during a refresh cycle using an average vector length of 8 mils. The refresh graphics can only be used where long vectors are applicable such as marking specific features for recognition purposes. Up to a meter of long vector data can be drawn without flicker. The 32-mil spot size of the refresh graphics preclude their use for accurate input, however. The refresh graphic coordinate system is addressable at 40X, the resolution of the stored graphics or a 1.6-mil grid, still twice the resolution of any off-the-shelf refresh tube. The refresh graphics are directly super-imposed on the stored graphics. No alignment error exists since the same deflection systems are used to generate both refresh and stored images. The refresh image is drawn in blue and is therefore distinguishable from the stored image.

(2) Major Components and Characteristics

Figure IV-7 illustrates the physical layout of the HRD-1. The keyboard will be removed from the HRD-1 console and placed on the digitizer table in order that the table may be pushed flush against the right portion of the HRD-1 console.

(a) HRD-1

- o Price $125K, F.O.B. London
- o Display Area 39.4" x 25.6" (100 x 70 cm)
- o Line Characteristics
  - Black Lines in Storage Mode
  - Blue Lines in Refresh Mode
  - Orange Background
- o Addressable Resolution
  - At film plane .000039" ($\leq$ 1 micron)
  - At display plane .00039" ($\leq$ 10 microns)

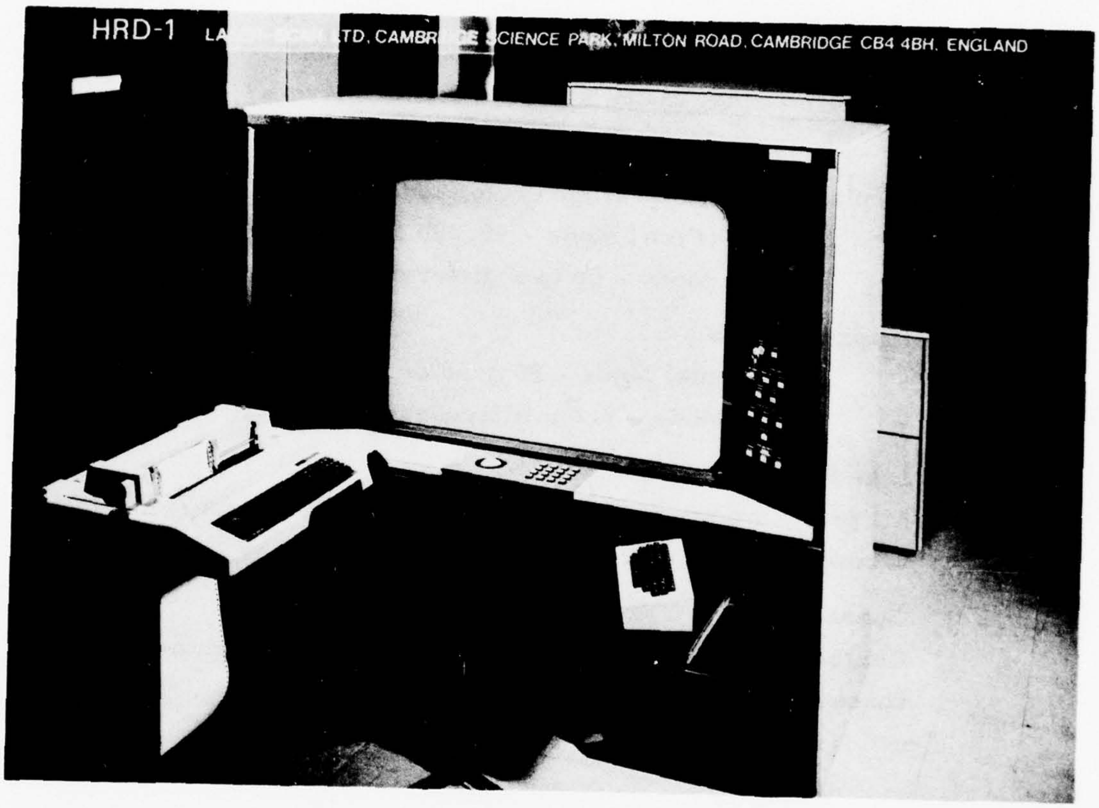

Figure IV-7 HRD-1 Console

- o Spot Size
  - At film plane ≤ .0007" (≤ 20 microns)
  - At display plane ≤ .007" (≤ 200 microns)
  - Refresh Mode ≤ .028 (≤ 800 microns)
- o Display Capacity (average vector length .008")
  - Storage (Film) Mode - 90,000 inches
  - Refresh Mode - up to a meter of long vector data
- o Display Speeds
  - Incremental Mode - 80 μsec.or 160 μsec. /vector triplet
  - Vector Mode - 2.2 milliseconds per vector
- o Line Styles

  All permutations of dash, dot and spaces for lineal symbology are hardware generated.
- o Character

  Character sets are defined in software. Hardware performs character string rotation, translation, and scaling.

- o Intensity - 1024 levels of intensity
- o Variable Function Keyboard - 16 keys
- o Typewriter Keyboard - 138 keys
- o Tracker Ball
  - 200HZ clocked interrupts
  - Range per interrupt = .000039" intervals from 0 to .005"
- o Hardcopy

  Diazo Film is output from the HRD-1. The exposed Diazo film which can be handled in daylight, is developed by exposure to hot ammonia in a simple desk top machine. The polarity of the recorded image and the extremely high resolution of the diazo film makes the recorded image excellent for reproduction and enlargement. In addition to standard office viewer/printers, which produce convenient hard copy for edit purposes at low cost, high quality enlargers and automatic developing systems currently available on the market can be used to produce the best enlargements in a few minutes for review plots.

(b) <u>Graphic Digitizer</u>

- o Price: $18K
- o Purpose:
  - Off-line digitizing of input data
- o Table Size - 42" x 58"
- o Basic Resolution - .002"
- o Overall Accuracy - ± .005"
- o Repeatability - ± .002"
- o Recording Resolution - multiples of basic resolution

(c) Alphanumeric Display

- o Price: $3K
- o Purpose:
  - to provide rapid display of all man/machine dialogue, control directives as required, feature description lists, and file summaries.
- o Display Time - 1.0 second
- o Format - small size CRT which displays 20 lines at 60 medium/large characters per line.

3. Trade-Offs

Summary

Advantages	Disadvantages
Extremely High Resolution Display	Medium High Risks
Extremely Large Display Capacity	High Cost
Relatively Small Spot Size	Slow speed
Large Format Display	Limited Refresh Graphics
Hardware Implemented Lineal Symbology	Single Line Weights
Hardware Implemented Alphanumeric Rotation and Scaling for Multiple Type Styles	Limited Color Capability
Variable Gray Shades and Line Weights	
Integrated High Speed Hard copy Plot	
Integrated Variable Function Keyboard	

Integrated Track Ball

Integrated Alphanumeric Keyboard

Mutliple Applications (see below)

Complete FORTRAN Programming Support

The HRD-1 is the only graphic display device which is capable of displaying an entire JOG chart at 1X in cartographic precision. The entire chart would require approximately 1.6 minutes to write. This write time is excessive for most interactive work, however, the cartographer will need to view the entire chart data set when performing an operation which affects the overall appearance of an area or the entire chart.

The majority of interactive data manipulation is performed on a small subset of the chart data set. A standard CRT screen, for instance, might display a 10" x 10" area. A medium density chart area displayed at 1X would contain 2000 inches of data; at 2X only 500 inches would be displayed in the same area. The display time for the HRD-1 would be 20 seconds and 5 seconds, respectively. These times are within the range for interactive data manipulation. It should also be noted that the 10" x 10" display would only occupy approximately 1/10 of the display screen. The rest of the display screen could be partitioned for use in displaying additional interactions of the updated display, thus avoiding movement of the photochromic film.

The use of a partitioned screen would also be valuable in comparing representations of modified or generalized features to the original or another alternative representation of the area. In effect, the user would have a similar capability as he would have if the system contained multiple CRT's.

The refresh mode is insufficient for most feature modifications such as edit or feature addition. The storage display would be updated whenever the refresh mode capacity was exceeded or confusion existed due to the presence of the identical feature in both refresh and storage modes.

The exceedingly high resolution and small spot size will allow data to be written on the photochromic film at 1/10X or less when full chart displays are desired. At 10X, the resolution is still less than 1.6 mils and the spot size is less than 8 mils, thus if data is written at 1/10X it can be viewed at 1X while maintaining the above resolution and size.

Point symbol and alphanumeric positioning and plotting could also be obtained through the use of the HRD-1. The HRD-1 provides hardware which performs symbol and alphanumeric translation, rotation, and scaling. Symbol libraries for type fonts are automatically referenced through the FORTRAN level subroutine support. The HRD-1 is capable of producing printed quality point symbols and alphanumerics for display or transparency production.

The large capacity of the HRD-1 provides the user with the ability to plot the entire chart in final symbology and alphanumerics if the symbolization and names placement systems have access to the device. The plot capacity is approximately 90,000 inches. The ability to review and make final corrections in lineal, digital format would be important in reducing final edits and touch-up.

The production of the center line water coat proof appears to be within the realm of reality through the use of the HRD-1 diazo copy. The feature class associated with a given color could be displayed and copied. The enlarged transparencies could then be registered to produce the water coat proof. It may be possible to even produce final color separations for printing if the diazo film is of sufficient quality for a 5X enlargement. These plots require only three minutes.

In summary, the HRD-1 Compilation Station has the important advantage of providing a display device which is capable of displaying and manipulating the data for an entire chart. It also has the advantage of producing hard copy transparencies.

On the negative side, display speeds are significantly limited, display updating is awkward, and some negative human factors exist. The speed and updating problems have been discussed above. The human factors problems can be isolated into two areas: (1) contrast and (2) the fresnel lens. The orange background is quite bright and the line work appears gray, not black, against this background. This contrast could be improved if the display is used in a low light environment. A fresnel lens is used as a projection screen for the HRD-1 display. The concentric lines on the lens cause the displayed graphics to appear somewhat fuzzy when projected. However, the user seems to become accustomed to viewing the screen and this slight distortion becomes less apparent. The fresnel lens also causes the illumination to vary, depending on the angle of the user to the screen. The illumination is sufficient, however, regardless of the varying intensity.

The lack of display speeds must be evaluated against the advantages of the large format, high resolution display, and the versatility of the HRD-1 within the entire ACS environment.

(4) System Operations

The HRD-1 configurations vary little in operation from the interactive operations discussed in Section IV-C-3-b. The primary difference will be in the use of the graphic display for highly interactive functions such as Feature Manipulation and Generation. The user must consider the relative lack of writing speed combined with the requirement to rewrite the entire display screen. He must be careful to limit the amount of data he wishes to display for interactive procedures and also limit the number of times that the display must be rewritten. The user will decrease the display writing time by reducing the data and will eliminate frequent time consuming (1 second) moves of the photographic film by limiting the number of display requests. Therefore, the use of the HRD-1 in truely dynamic functions (e.g., feature modification) is impractical under the above restrictions.

Feature Modification and Generalization will be performed upon more of a trial and error basis rather than a dynamic procedure as indicated in the general discussion.

The HRD-1 will, however, provide a large scale display and high speed proof plot capability not available as functions in the General System Operations. These two functions will eliminate the requirement for frequent off-line plots and increase the users' awareness of the status of the product compilation.

e. Refresh CRT/Graphic Digitizer Station Configuration

(1) Distinguishing Characteristics

The major characteristics of this configuration are: two primary devices (i.e., graphic display and digitizer table) are employed for performance of compilation activities; highly dynamic and flexible interactive capabilities of the CRT device; limitations to the amount of feature information which can be displayed at one time, and hardware upgrade potential in areas of display capacity, variation of spot sizes, and finer addressable resolutions.

This configuration will rely heavily upon graphic plots to present symbolized and/or line center representations of the total product area. These plots will provide an off-line vehicle for compilation planning and annotation of actions at the compilation station. Due to the importance of quality plots to this configuration concept, consideration should be given to techniques for generating plots in the most responsive manner. Placing the plotter on-line to the Station Support System would probably be the best approach.

(2) Major Components and Characteristics

- o Graphic Refresh CRT
- o Graphic Digitizer
- o Alphanumeric Display
- o Alphanumeric/Function Keyboard
- o Cursor Devices

(a) Graphic Refresh CRT

- o Quality Display Area - 10" x 10"
- o Display Speed - ≈ 1 short vector/μs (33,000 per 1/30 second)
- o Line Characteristics:
  - Center line - use of at least 2 variable intensity levels available for interpretation
  - 4-color optional at sacrifice in spot size (≈ 50% increase)
  - Dashed Line
  - Dash/Dot Line
  - Line Width[1] - 1 size (8 to 12 mils depending on specific refresh CRT)
- o Addressable Resolution[2] - 5 mils (2048 x 2048 elements)
- o Vector Size[3] - variable from ≈ 5 mils (increments of ≈ 5 mils)
- o Display Volume[4] - up to 33,000 Vectors (see table below)

Average Vector Lengths	Lineal Inches (33K Vectors)	Square Inches Displayed (at area density of 20"/square inch at 1X)		
		1X	2X	3X
.005	165	8.25	16.5	24.75
.010	330	16.5	33.0	49.50
.015	495	24.75	49.5	74.25
.020	660	33.0	66.0	99.0
.025	825	41.25	82.5	123.75
.030	990	49.5	99.0	148.5

Notes:

(1) Variable spot sizes (at least 3) can be achieved within current state-of-the-art.

(2) Addressable resolution can likely be improved in the future to 4K x 4K.

(3) Vector size (minimum) could be reduced to ≈ 2.5 mils if higher addressable resolution is available.

(4) Potential increase (200%+) in display capacity by employing higher speed memory (currently 990 nanoseconds), tighter packing of vectors, and/or a dedicated display processor.

In summary, the refresh CRT could display approximately 330 inches of feature information assuming an average vector size of 10 mils and 16.5K words of storage at 2 vectors per word. At a density of 20 inches of feature data per square inch, a 4" x 4" display could be generated. The same data magnified by 2X could fill an 8" x 8" display area, magnified by 3X could more than fill 10" x 10" display area.

(b) <u>Graphic Digitizer</u>

- Purposes:
  - Laying out product data base plots and supplementary graphic materials
  - Vehicle to define location of areas to be displayed on graphic CRT
  - Digitizing of supplementary/update feature information from graphic source materials
  - Defining location data for feature manipulation and generalization actions
- Table Size - 42" x 58"
- Basic Resolution - .002"
- Overall Accuracy - $\pm$.005"
- Repeatability - $\pm$.002"
- Recording Resolution - multiples of basic resolution

(c) Alphanumeric Display

- o Purpose - to provide rapid display of all man/machine dialog, control directives as required, feature description lists, and file summaries.
- o Display Time - 1 second
- o Format - small size CRT which displays 20 lines at 60 medium/ large characters per line.

(3) Trade-Offs

(a) Functional/Operational Prowess

The refresh CRT configuration is highly responsive to the functional requirements of the station because of its inherent display dynamics and speed. All displays, once the display file is generated, will be instantaneous. Generation of the display file will be comparable with other display systems, as time will be dependent on fetch time, special processing and formatting time, and time to pass the data to display memory. Operationally the station sacrifices some throughput potential and raises a human factors problem because of limitations to the display capacity and associated display area (maximum 10" x 10" display and in extremely dense areas a 4" x 4" display), thus requiring more display interaction to cover a complete product area. A question concerning this point is; how beneficial is the ability to display large areas (i.e., greater than 10" x 10") on the CRT? Except for general comprehension while starting to work an area and near the end for, again, a comprehensive impression of the end product, this station configuration satisfies the overall area presentations via graphic plots, as required.

A major constraint of all immediately available refresh CRT's is the capability to display cartographic quality at 1X. The above configuration requires at least 2X magnification to maintain cartographic precision. The major contributing factors to this deficiency is addressability and spot size. While enlargement is desirable for performing some type of compilation actions to offset this immediate deficiency, at least one vendor indicates that smaller spot sizes (i.e., approaching the addressability) and variable spot sizes can currently be achieved; also, improvements to the addressability is nearly achievable. The potential of upgrading the original display hardware without requiring system or software redesign is a strong benefit and should definitely be considered.

(b) Station Costs

The primary hardware costs for this station would be for the refresh CRT and associated mini-processor, graphic digitizer table, and alphanumeric display device. Representative costs for these devices are as follows:

Item	Dollars ($1,000)
- Refresh CRT with 32K Memory, Interface Unit, Cursor Control Device, and other associated display support options.	44*
- Graphic Digitizer Table with Interface Unit and Cursor Devices.	18
- Alphanumeric Display CRT with keyboard.	3
	65

(c) Technical Risks

All items proposed for this configuration are within the state-of-the-art and have been demonstrated individually in related application areas. The only minor risks are associated with special hardware refinements to the refresh CRT system, if such options are requested for the first model. The multiple line weight and spot size refinements are minor technical risks since they have been achieved on test models. The higher addressability and associated smaller vector sizes are stated as being technically feasible although further testing is warranted.

(4) Proposed Alternate or Upgraded Refresh CRT Model

Display Hardware

4K x 4K Addressability (≈ 2.5 mils)

3 spot sizes (5, 10, 15 mils)

32K display buffer memory

*IMLAC has stated that they can provide special electronics and other necessary hardware to achieve: 4K x 4K addressability, variable spot sizes, flexible hardware symbol generator, and significantly higher display capacity for approximately \$45K - \$60K (60% - 70% of which is one-time engineering costs). Additional display memory would also be required.

16K processor memory

≈ 500 ns/vector (short) display speed

Cost (Increase)

Special Electronics Development	\$50,000 (includes one-time cost of ≈ \$35,000)
Additional 16K Memory	\$10,000
	\$60,000 (≈ \$25,000 for subsequent models)

Improved Capabilities

Multiple Line Weights

Twice the display capacity:

64,000 short vectors (2 vectors per word)

32,000 medium vectors (1 vector per word)

16,000 long vectors (1 vector per 2 words)

Cartographic quality displays at 1X

(5) System Operations

All operations as described in Section IV-C-3-b. can be performed on the refresh CRT configuration. The system has limited display volume and an overly large spot size, however. This will cause a greater degree of chart area definition and display requests, as well as display scaling change requests, to be made by the operator during his interactivity with the graphic CRT.

f. Video Display Compilation Station Configuration

(1) Distinguishing Characteristics

Compared with the Refresh CRT compilation station this configuration exhibits higher data volume handling capability (but not necessarily displayable), easily applied use of colors, and gray levels, unlimited line type, and a need for greater processing overhead.

(2) Major Components

Except for the display device itself, the major components are essentially the same as those in the Refresh CRT configuration. One additional exception might be the method (and thus the component device) of achieving interaction with the data file. This topic is discussed below.

(a) Video Display Characteristics

- o Quality display area: 10" x 10"
- o Display speed: limited by input rate
- o Line characteristics:
  - Raster format; line type essentially unlimited
  - Gray levels
  - Colors
  - 10-20 mils minimum width
- o Effective addressable resolution: 10 mils
- o Display volume: essentially unlimited, but at a rapid reduction in cartographic and visual quality.

(3) Trade-Offs

(a) Requirements Responsiveness

The various types of video display units ("Graphic CRT Devices") offer high data handling densities, color, brightness, picture quality, and rapid update cycles. Thus they meet the design requirements of data volume handling, response times, and some aspects of display interpretation.

Because of their spot sizes (10-20 mils) and their display resolution (1000 lines at best), the effective visible display cannot meet the more stringent display requirements of 4-8 mil line widths at a scale factor of 1X, or even 4-mil display addressable grid intersections at a scale factor of 2X. Thus CRT accuracy design parameters are not met sufficiently to display the required cartographic quality. A full map format size cannot be displayed at scale on these devices.

(b) Software

All but one of the vended devices require an extra software module that must convert the lineal feature data files to the required raster format for display purposes, thus increasing software storage and processing time.

An additional high-overhead module, necessary for all video devices, would have to be developed that would allow interactive manipulation of the lineal feature data files via the raster-formatted display. Until the methodology of this function is determined, the type of display point-locating device (light pen, joystick, etc.) cannot be identified.

Also, when one of two intersecting lines is erased, the common points of the intersection are erased, thus obliterating a segment of the line that is meant to be retained. Since a refill of the missing segment is immediately necessary; additional software must be provided to recognize and correct that situation.

(c) Station Costs

The major hardware costs for this station are for the video CRT monitor and associated miniprocessor, graphic digitizer table, and special support devices.

Item	Dollars
Video CRT monitor, A/N keyboard, display electronics, interface, miniprocessor (48K) and cursor control	$35,000
Alphanumeric Display Console	$ 3,000
Graphic digitizer table with interface and cursor devices	$18,000
Special function keyboard with interface	$ 7,200
	$63,200

(d) Technical Risks

Few risk factors are evident by using the video system, although the Silicon Storage Tube is a recent innovation and thus unproven. Development is being conducted by a number of companies to continually improve video display quality and capabilities.

(4) System Operations

All operations performed on the refresh configuration can be performed on the video system. An additional necessary operation, if not handled completely by software, would be that of identifying those obliterated feature segments due to one of two intersecting lines being deleted.

g. HRD-1 and Refresh CRT Hybrid Configuration

(1) Distinguishing Characteristics

The HRD-1 Console provides a large scale, high resolution display. The primary drawback with the HRD-1 is the lack of drawing speed which in turn negatively affects display dynamicism. The refresh CRT, on the other hand, has a high degree of dynamicism with limited resolution and data capacity. The integration of these two devices into a single system will provide large scale, high resolution, and high interactivity display capabilities. This will be accomplished by performing operations which require a high degree of interactivity on the refresh CRT (such operations would primarily involve modifications to plotted features) while using the HRD-1 to display the working data base.

The refresh CRT will display only the local area which affects the particular feature or features being modified. The modified area can then be integrated into the HRD-1 large scale display upon operator request. Often it will be possible for graphic manipulations to continue on the refresh CRT while the HRD-1 plot is being updated, thus reducing wait times induced by the HRD-1.

The existence of the HRD-1 in the system will eliminate two of the major objections to CRT-based systems. The primary problem of data display limitations will no longer exist since the user will be able to view the entire area on a large display device. The lowering of data requirements on the refresh CRT will also eliminate some of the processing and storage restrictions of the refresh processor, since it will not be necessary to process large amounts of data during the display cycle, or to maintain large display lists. The second major problem of the refresh display configuration is the degradation of the plot which is used for the overview of the area being compiled. The refresh configuration requires the plot to be registered to the data files. As the compilation process progresses (i.e., features are added, deleted, re-oriented), the plot no longer reflects the

contents of the working data base. A new plot must be generated often causing a significant delay. The HRD-1 display will eliminate the delay since the plot can be updated in approximately two minutes to reflect the current working data base status.

Some operations which do not require a high degree of interactivity will be performed on the HRD-1. Deletion is an excellent example of an HRD-1 oriented operation. Features could be selected for deletion using the HRD-1 cursor and track ball or the digitizer cursor. A blue "X" or some other indicator would be generated by the refresh graphics of the HRD-1 to mark the features to be removed. The operator would continue selecting features for deletion until he wished to view the updated file at which time he would call for a new HRD-1 display.

(2) Major Components

(a) HRD-1

(See HRD-1 Compilation Station for specifications.)

(b) Graphic Refresh CRT

(See Refresh/Digitizer Station Configuration for specifications.)

(c) Graphic Digitizer

(See Refresh/Digitizer Station Configuration for specifications.)

(3) Trade-Offs

The HRD-1 and Refresh CRT Hybrid Configuration presents the most nearly optimal configuration to perform the compilation task. The weaknesses of each device are supported by the strengths of the other. There are, however, three major drawbacks in the hybrid configuration: 1) human factors, 2) cost, and 3) software overhead.

The human factors are negatively affected by the introduction of a third graphic viewing plane. The physical size of the HRD-1 prevents it from being mounted above the digitizer table. Therefore the user's attention must be directed away from either the digitizer or the refresh CRT to determine the effect of his action on the HRD-1 display. This problem may

prove to be inconsequential but certainly is a potential drawback if the user must spend a good deal of his time glancing back and forth among devices.

The hardware cost per station of the HRD-1 and Refresh CRT Hybrid Configuration can be broken down by device.

HRD-1	$125,000	FOB London
Refresh CRT	$ 44,000	
Graphic Digitizer	$ 18,000	
	$170,000	

It should be noted that the HRD-1 requires an associated processor. It is expected that a host processor will be capable of providing intelligence to the HRD-1 without an additional dedicated processor. The refresh CRT price does include a processor. It can be seen that the hybrid system is significantly more expensive than either of the preceeding configurations. This cost reflects significant overlap in the hardware functions of both the HRD-1 and the refresh CRT. The hybrid configuration will, however, be more responsive to the compilation problem and more flexible in its use by the station operator.

The hybrid configuration will require additional software to support two graphic displays. Analysis of the display formats will determine whether multiple formats will have to be retained or whether a common format will service both displays and be converted before transmission to the device. In either case additional software is required for data base support or conversion. The duplicity of control between devices will also increase the required software. Software overhead will materialize as additional cost.

(4) HRD-1 and Storage CRT Hybrid Configurations

A storage CRT such as the Tektronix 4014 could be substituted for the refresh CRT. Two advantages could be obtained by use of a storage CRT; 1) the storage CRT could display an unlimited amount of graphic data, and 2) the CRT cost would be reduced by approximately $30,000. The primary drawback in using a storage CRT is the lack of I/O speed. The existing

high speed interfaces for the storage CRT's would be sufficient to maintain relative interactivity for most compilation functions. However, true dynamic man/machine interfaces would not be possible with the HRD-1 and storage tube configuration.

Dynamic man/machine interfaces include such operations as feature pulling, cursor tracking, and alphanumeric rotation. A refresh CRT would allow the user to interactively stretch or pull features using the cursor. The user could continue modifying a feature until he was satisfied with its position without erasing and replotting the entire screen for each positional change of the feature. Cursor tracking for feature input and modification, and alphanumeric character string rotation, also requires continual display updating iterative techniques are used, and therefore requires the use of a refresh CRT. Thus, there exists a direct tradeoff between interactivity and display volume plus cost.

Summary

Advantages	Disadvantages
Extremely High Resolution Display	Medium High Risks
Extremely Large Display Capacity	High Cost
Small Display Spot Size	Single Line Weights
Large Format Display	Limited Color Capability
Hardware Implemented Lineal Symbology	Software Overhead Unevaluated Human Factors
Hardware Implemented Alphanumeric Rotation and Scaling for Multiple Type Styles	
Variable Gray Shades	
Integrated High Speed Hardcopy Plot	
Integrated Variable Function Keyboard	
Integrated Track Ball	
Integrated Alphanumeric Keyboard	
Multiple Applications	
Complete FORTRAN Programming Support	
Highly Interactive	

(5) System Operations

The HRD-1 and Refresh CRT Configuration follows the operational flow as with the General System Operations discussion in Section IV-C-3-b. The use of the HRD-1 will provide an immediate feedback of the compilation data base status. It is expected that the refresh graphics of the HRD-1 will be used to create a rectangle which will define the area which is being displayed on the refresh CRT. A capability to show 1) the digitizer cursor position on the refresh CRT and HRD-1 screens, and 2) the refresh CRT cursor position on the HRD-1 screen will be provided within the system. The above capabilities will allow the user to easily correlate a particular area of interest across all graphic devices.

Interactive operations which require only feature selection thru pointing, can be easily performed via use of the HRD-1 refresh graphics. Examples of such functions are delete, clip, and join. The HRD-1 refresh graphics are adequate for feature identification and/or approximate locating. The use of the HRD-1 for deletion in the early phases of compilation will be particularly efficient. The use of this large scale display will provide the user with a means of selecting features for deletion over the entire chart without requesting additional displays of subareas. Thus feature density can be considerably reduced before the compilation requires the use of the refresh or storage CRT's for detailed work.

h. Storage CRT Configuration

(1) Distinguishing Characteristics

The storage CRT configuration is identical to the Refresh CRT Configuration with the exception that the storage CRT replaces the refresh CRT. The storage and refresh CRT technologies reflect a basic trade-off between display capacity and dynamics. The storage tube has a virtually unlimited display capacity but the entire display must be rewritten when a single displayed line is modified. The refresh tube can easily modify a line but can only display the number of vectors which can be drawn in 1/30 second.

Currently, two manufacturers are producing complete storage CRT packages. These are TEKTRONIX and DICOMED. The TEKTRONIX 4014 is the most sophisticated device in the TEKTRONIX product line. This device will be considered in the Storage CRT configuration. The DICOMED D36 CRT, while having superior resolution, spot size, and intensity, must be discounted because of its screen size, plot speed, and erase times. The DICOMED D36 is a 7" x 7" CRT, whose average image writing time is two minutes, and whose erase time is 20 seconds. The erase time is particularly objectionable since the 20-second delay exists regardless of screen content. This would require a nearly 2.5 minute wait time for a line modification on a dense display.

(2) Major Components and Characteristics

(a) Storage CRT - TEKTRONIX 4014

- Display Area - 15" x 11" (165 sq. in.)
- Drawing Speed - 5000 inches per second plus 10-15 microseconds per vector.

Note: A standard 307K baud teletype interface exists for certain minicomputers. This is the fastest standard interface available. However, some of the newest mini's are limited to only a 10K to 20K baud interface due to the level of circuit integration within the input/output port.

A DMA port is available for use. It is called a General Purpose Parallel Interface by Tektronix, but is apparently a custom interface which has a fairly high risk factor. Speeds of up to 300K bytes per second might be expected.

Speed of the TEKTRONIX 4014 is dependent on both the vector drawing speed and the I/O speed. Parallel fetch and drawing operations are possible due to a pseudo-hardware buffering which allows for all but the last byte of the five-byte addressing scheme to be loaded before completion of processing the previous vector. Thus only a single byte must be transmitted before drawing of the next vector may be initiated.

The time required to plot a full screen could be estimated as follows:

A medium display is 20 lineal inches/sq. inch. This is 165 sq. inches on the Tektronix 4014 screen.

$$\frac{165 \text{ sq.}}{\text{in.}} \times \frac{20 \text{ lineal inch}}{\text{sq.}} = 3,300 \text{ lineal inches}$$

An 8-mil vector can be drawn in approximately 30 μsec.

$$\frac{3,300}{\frac{8 \times 10^{-3} \text{ in.}}{\text{vector}}} = 412,500 \text{ vectors} \times 30 \times 10^{-6} \text{ sec.} \quad 12 \text{ sec.}$$

- o Line Characteristics
  - Center Line - use of at least two intensity levels
  - Dotted Line
  - Dash Line
  - Dot/Dash Line
  - Line Width - 1 size (10-mil spot size)
- o Displayable Resolution - 3.6 mils (4096 x 4096 elements)
- o Vector Size - all sizes (absolute addressing mode)
- o Display Volume - unlimited

(b) Graphic Digitizer

(See Refresh CRT Configuration for Graphic Digitizer Specifications.)

(c) Alphanumeric Display

(See Refresh CRT Configuration for Alphanumeric Display Specifications.)

(3) Trade-Offs

The strong advantages of the storage CRT are the display capacity, resolution, and cost. The display capacity, as mentioned above, is virtually unlimited. The number of distinguishable lines is only limited by the 10-mil spot size. The 15" x 11" storage CRT will also yield a larger display than the refresh.

Station costs are as follows:

TEKTRONIX 4014	14K
Graphic Digitizer Table	18K
Alphanumeric CRT	3K
	35K

The storage CRT represents a cost savings of $30,000 per station when compared against the refresh CRT configuration.

The storage CRT technology produces several undesirable effects.

- Tektronix states the intensity at 8-10 foot/lamberts for the TEKTRONIX 4014. Military specifications require 25 foot/lamberts for CRT displays. The reduced intensity will tend to cause eye strain during long usage.
- Line width is variable depending upon spot position on the screen. The spot size is 10 mils at screen center and 14 mils at the screen edges. Therefore, it is possible for two lines to coalesce in one position on the screen, but be separated in another portion. This is a particularly undesirable trait for CRT displays used in cartography.

- The erase function of the storage CRT also entails some undesirable features. The TEKTRONIX 4014 flashes the screen during each erase. This flash could be tiring to the eye over long periods of use.
- The 10-mil spot size is considerably larger than the optimal 4-mil spot size and there is little hope in reducing the storage CRT spot size due to an unacceptable loss in intensity.

In final analysis, the cost and data capacity advantages must be evaluated against the low intensity on a 10-mil minimum spot size available on the storage tube.

(4) System Operations

The Storage CRT Configuration follows the same basic systems operations procedures as outlined in the General Systems Operations. The lack of dynamic display capability of the storage CRT will eliminate the usage of such techniques as dynamic feature modification. Dynamic functions will have to be performed on a trial and error basis in which the entire screen is replotted for each modification. These considerations do not alter the basic compilation procedures, but only the manner in which particular functions are implemented.

4. Source Assessment/Data Extraction Design Analysis

a. Conceptual Approaches

A number of technical approaches were identified which offer a wide range of concepts and which appear viable in terms of technology state-of-the-art.

Concept 1 - Assessment Via Digital Sampling.
Concept 2 - Image Scanning and Rectification.
Concept 3 - Optical Transformation and Image Display.
Concept 4 - Photographic Rectification and Image Display.
Concept 5 - Digital Plot and Image Projection.

Each of the concepts possess unique technical approaches and will provide various levels of compliance with the requirements and associated trade-off factors. Each of the design concepts are presented below with the intention of conveying the conceptual approaches and configurations, hardware/software implications, and salient trade-off considerations. Most of the approaches primarily are concerned with the assessment problem with provisions for the data extraction process when feasible.

(1) Concept 1 - Assessment Via Digital Sampling

(a) Description and Characteristics

This design concept represents a basic approach to performing the source assessment function. The concept is based on the premise that by sampling a few major features, or features representative of a particular class, a compiler could assess a graphic source to a sufficient level. Digital feature data and raw source graphics could be brought directly to the Graphic Compilation Subsystem, reference parameters entered for each source, and sample features digitized from applicable sources. Digitized features would be transformed to the compilation projection and scale. Composite displays of digital feature information based on identical reference

frames could then be presented to the user for assessment. Determination of further digitizing requirements and other compilation planning would then be performed by the compiler.

One of the major attributes of this approach is that no hardware devices or major software functions would be required beyond these defined for the current design concept of the interactive subsystem.

(b) Major Components

- o Graphic Digitizer
- o Graphic Display Device

(c) Process Flow

See Figure IV-8.

(d) Major Trade-off Factors

o Responsiveness to Requirements - provides for accuracy necessary to precisely compare features from divergent sources and digital files; limitation is that any feature to be compared must be digitized, thus limiting the detailed assessment to only a sampling. This restriction therefore precludes the user from directly assessing all graphic source contents in an area without either: (1) digitizing all applicable data; or (2) transforming the digital data to the graphic source reference frame and producing a hardcopy plot. Large volume digitizing requirements would be conveyed back to digitizing systems; minor chart updates could be directly assessed and performed at the interactive subsystem.

o Compatibility with ACS - no impact, allows for source assessment and compilation to be performed at interactive subsystem.

o Development Factors - possibly addition of minor software routines to perform various levels of image transformation. Cost and technical risk would therefore be minimal.

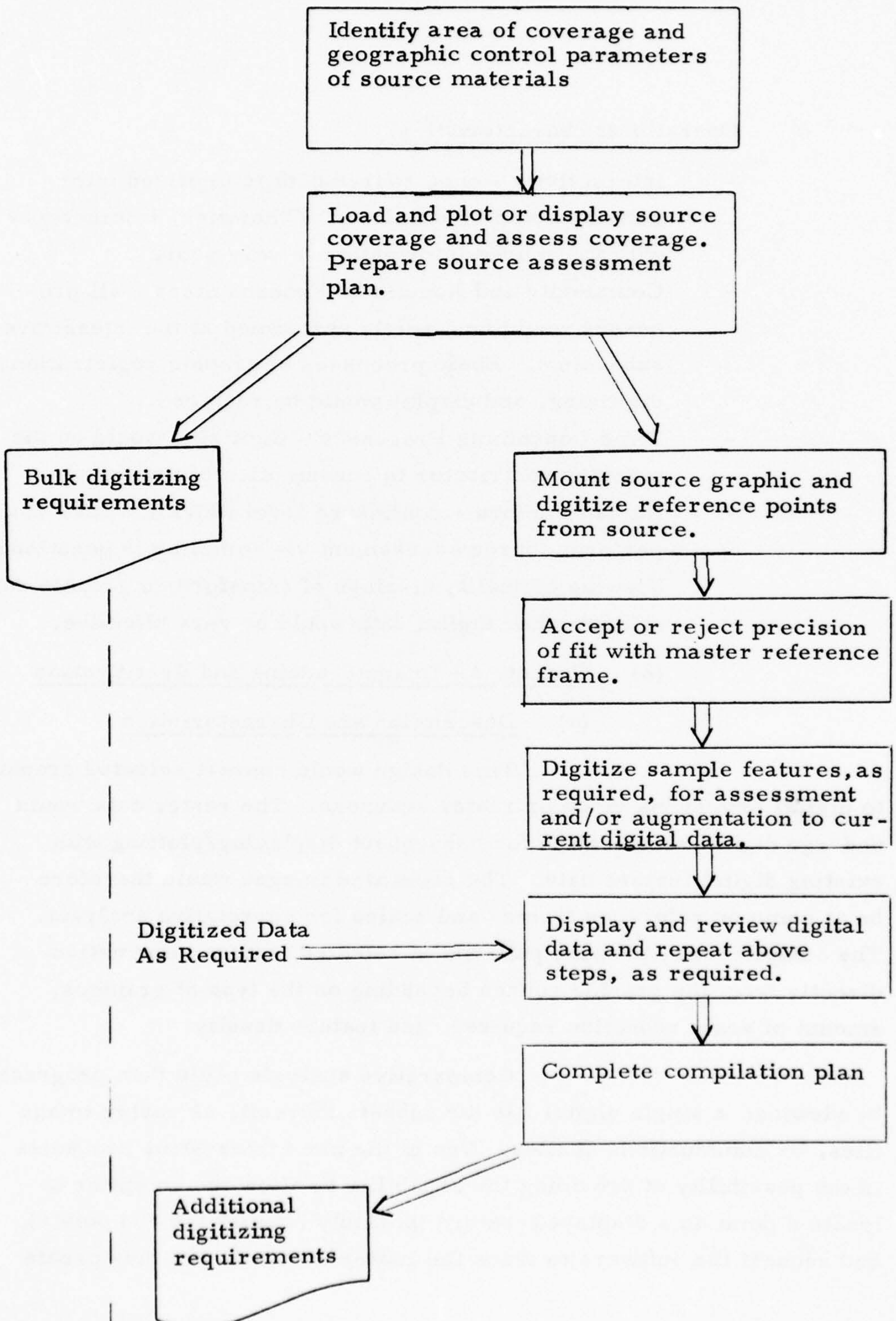

Figure IV-8 Concept 1 - Source Assessment Via Digital Sampling

o Operational characteristics

- Interactivity - once source data is digitized interactivity would be excellent. Otherwise, interactivity with the source information is very poor.
- Complexity and Number of Process Steps - all processes would be directly performed at the interactive subsystem. Basic processes of graphic registration, digitizing, and display would be required.
- Time Consuming Processes - digitizing would be the primary contributor to consumption of time.
- Human Factors - confidence level which the user can perform source assessment via sampling is questionable. Viewing of quality displays of transformed graphic data against other digital data would be very effective.

(2) Concept 2 - Image Scanning and Rectification

(a) Description and Characteristics

This design would convert selected graphics to digital format via video or raster scanners. The raster data would undergo digital rectification for subsequent displaying/plotting with existing digital feature data. The generated images would therefore be at common reference frames and scales for correlative analysis. The compiler may prepare pull-ups of selected feature information directly from the graphic source depending on the type of graphics, amount of scale reduction required, and feature density.

Comparative analysis could then progress by viewing: a single digital file (or subsets thereof), or raster image files, or combinations of files. One of the most interesting prospects is the possibility of providing the capability to allow the compiler to locate a point on a displayed feature (possibly identify the end points), and request the software to track the raster elements and thus create

a lineal feature. This capability would permit the compiler to extract feature information from various sources and thus create a digital compilation work file. Some level of feature filtering could be applied to the raster image files, depending on the source format and detection/coding system.

(b) Major Components

- o Video or Raster Scanner
- o Matrix Plotters
- o Raster and Lineal/Vector Display System

(c) Process Flow

See Figure IV-9.

(d) Major Trade-off Factors

o Responsiveness to Requirements

- Provides accuracy of feature positioning because of digital transformation.
- Inherent possibility to directly create lineal strings of selected features from raster elements.
- Possibility of extreme clutter of information, depending on extent of filtering possible, resulting from image scanning and scale reduction.

o Compatibility with ACS - graphic display system must be capable of high volume plotting of raster data combined with lineal feature data. Image scanning and raster processing systems would be required.

o Development Factors - design of a raster/vector display system; development of raster transformation capabilities.

o Operational Characteristics

- Interactivity - high level of interactivity since all data (lineal and raster) would be digital at the display system.

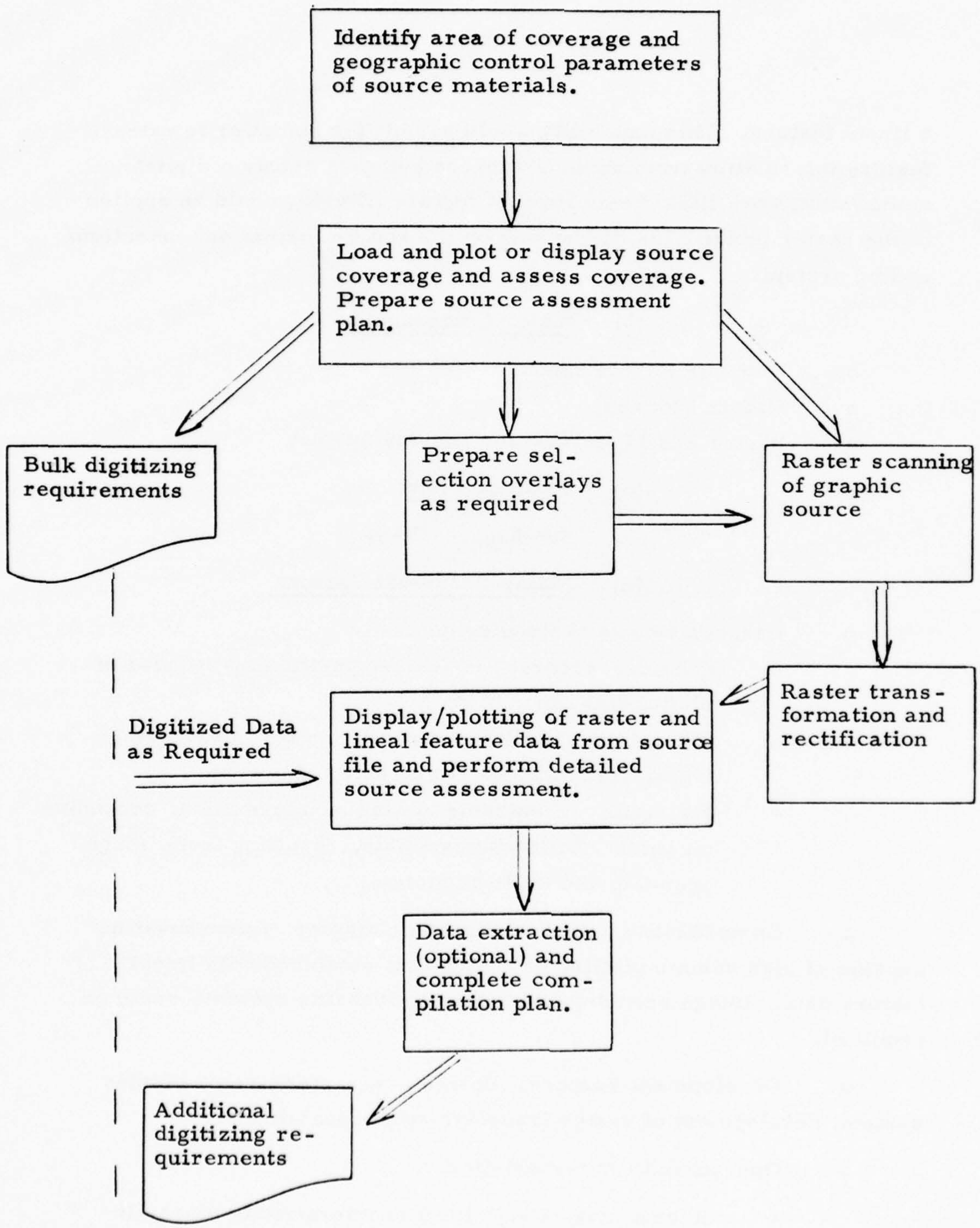

Figure IV-9 Concept 2 - Graphic Scanning & Rectification Concept

- Complexity and Number of Process Steps - several complex processes would be required prior to actual assessment, such as: scanning, raster transformation, loading and displaying of high volume raster data.
- Time Consuming Processes - scanning and transforms would consume extensive resources for each source graphic.
- Human Factors - interpretation of transformed graphic would be a major problem.

(3) Concept 3 - Optical Transformation and Image Display

(a) Description and Characteristics

This design would rely on a hardware device which could simultaneously display digital feature data and project graphic information to a common viewing plane. The projection system would consist of necessary optics for performing scaling and transformation of images. Source graphics would likely be contained on standard microforms for ease of handling by the projection system. A microform cartridge containing all source graphics could be brought to the system for selective viewing and assessment. Consideration could also be given to using optical filters for suppressing certain colors of feature information on the source graphic. Critical factors to success of this design would be: accurate registration of the digital image with the graphic image; also the precision and effectiveness of optically transforming and fitting the source graphic to the desired projection reference frame.

(b) Major Components

- o Digital and Graphic Image Projection System
- o Micrographic System (optional)

(c) Process Flow

See Figure IV-10.

(d) Major Trade-off Factors

o Responsiveness to Requirements

- Superimposing a digital image with one or more graphic source images provides a high level of capabilities and flexibilities.

- Data extraction would require direct feature digitizing.

o Compatibility with Current System Definition - would require a large screen display system and associated image projection and control features. Probable approach would be either: definition of a separate subsystem; or else modification to interactive display system.

o Development Factors

- Digital/ optical display system and control mechanisms

- Software/hardware control for image(s) display and registration.

o Operational Characteristics

- Degree of Interactivity - provides for manual or mechanical change of source graphic for viewing. Possibility exists for filtering source contents based on color or area.

- Processes - to provide common graphic formats (microforms) to the projection system would require some level of photographic copying prior to performing the assessment function. Ease of registering superimposed image would be critical to overall operations.

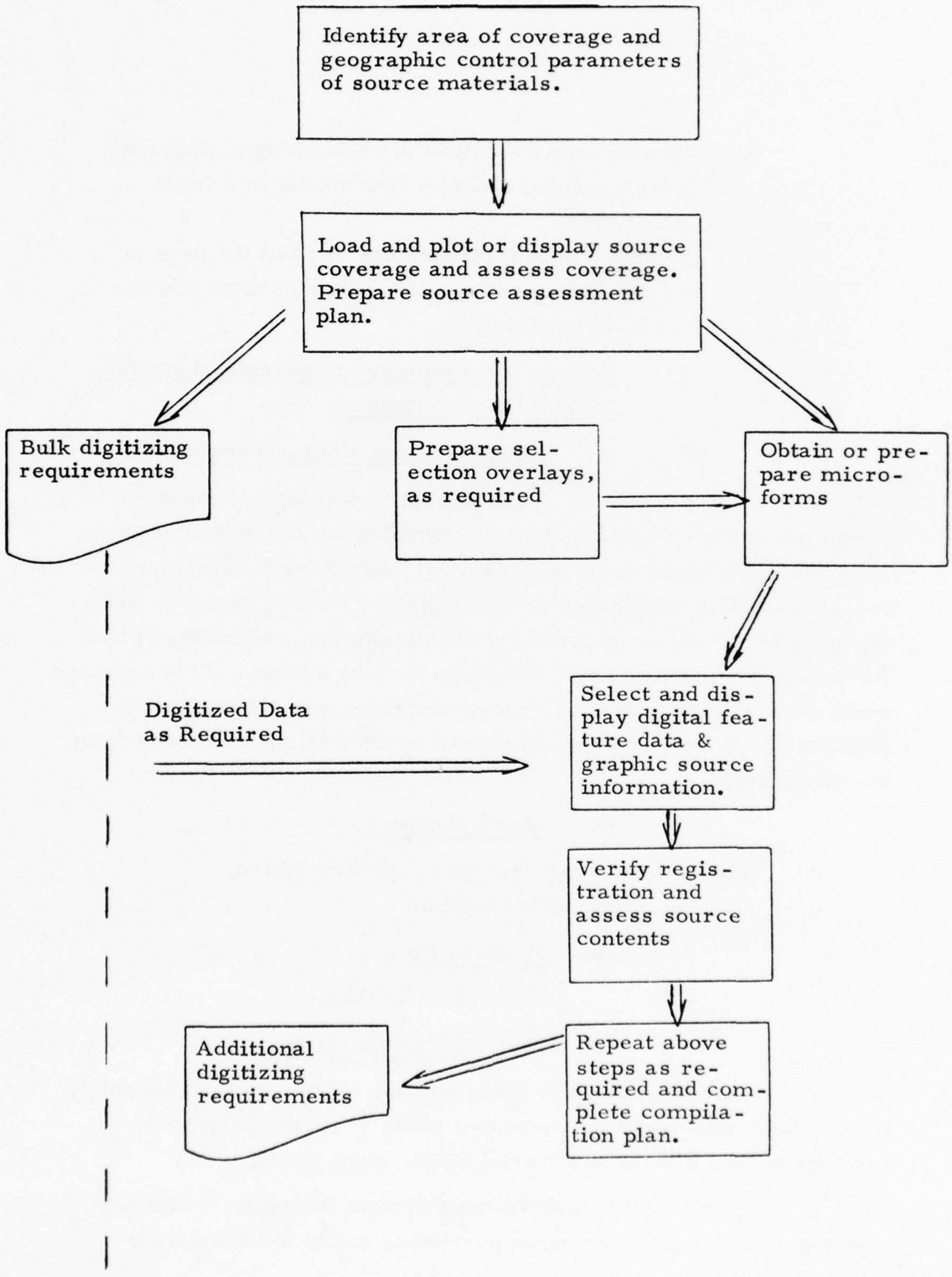

Figure IV-10 Concept 3 - Optical Transformation & Image Display

- Time Factors - delays in performing photographic preprocessing could be detrimental to overall throughput.
- Human Factors - techniques to allow the user to easily distinguish one source image from another would be critical.

(4) Concept 4 - Photographic Rectification and Graphic/Digital Display

(a) Description and Characteristics

This concept is similar to Concept 3, except the approach is to account for rectification of photo sources by employing a stand-alone photo-optical system for processing of the source materials prior to going to the graphic display system. This approach would reduce to technical complexities of integrating optical rectification components with the image display system. This approach would definitely require another step in the process, photographic rectification (which is currently viewed by DMAAC as time-consuming and expensive).

(b) Major Components

- o Digital and Graphic Image Projection System
- o Graphic Rectification Systems

(c) Process Flow

See Figure IV-11.

(d) Major Trade-off Factors

o Responsiveness to Requirements - same as for Concept 3, except that transformation techniques could be more specifically oriented to type of source material (e.g., map, photo, etc.).

o Compatibility with Current System Definition - same as Concept 3 except that a stronger possibility exists for effectively

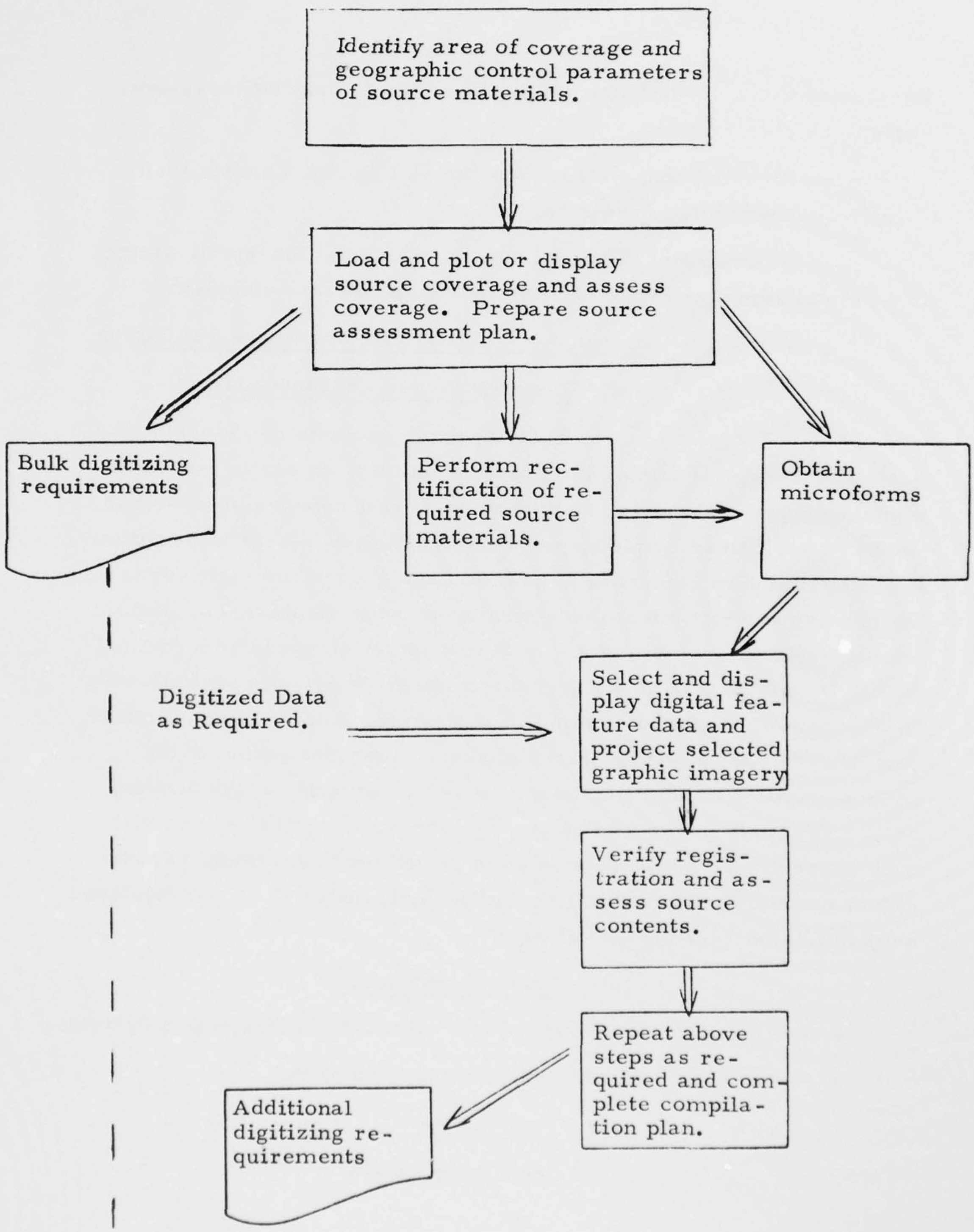

Figure IV-11 Concept 4 - Photographic Rectification and Graphic/Digital Display

integrating these capabilities within the current compilation system design.

o Development Factors - same as Concept 3 except less complex hardware requirements.

o Operational Characteristics - same as Concept 3, except that optical adjustments for assessment would be less complex.

(5) Concept 5 - Digital Plot and Image Projection

(a) Description and Characteristics

This approach consists of assessing the general coverage of digital and graphic sources, as performed in the other concepts. The primary difference is that detailed assessment would be performed by plotting of selected digital feature information in the compilation reference frame; and using a special digitizer table with an associated optical projection system for displaying of graphic sources onto the graphic plot. Again registration would be a critical design factor, in this case, graphic to image registration. Following assessment of digital vs. graphic sources the compiler could digitize selected features from projected images. Transformation of the source graphics could be achieved via optics directly at the station, or be previously processed by stand-alone photo-optical systems. Also if precise transformation was required for assessment verification a sample feature could be digitized, transformed, and displayed or plotted with existing digital data.

(b) Major Components

o Digitizer System and Associated Optical Projection System.

o Graphic Rectification Systems (optional).

(c) Process Flow

See Figure IV-12.

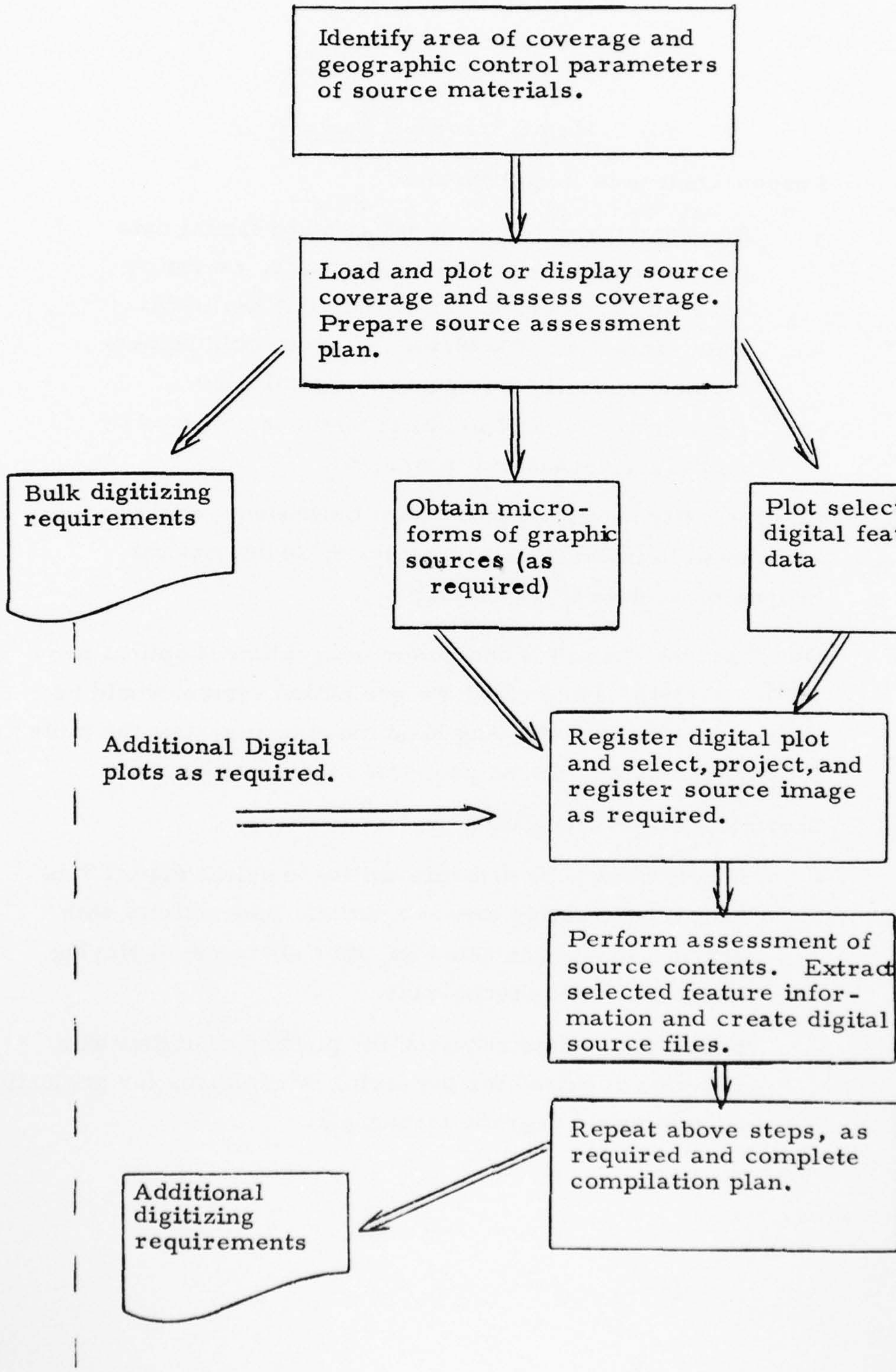

Figure IV-12 Concept 5 - Digital Plot and Image Projection

(d) Major Trade-off Factors

o Responsiveness to Requirements

- No dynamics in terms of selection of digital data for assessment with source graphics, except by mounting a separate plot on the digitizer table.
- Data extraction of selected features could be performed manually for update to digital file.
- Registration of plot to image could be achieved by software/mechanical techniques.

o Compatibility with Current System Definition - could be augmented to interactive subsystem by adding optical projection system to digitizer.

o Development Factors - design for integration of optical projection system. Preferably the projection system would be rear-mounted; thus allowing hand movement across the table for the digitizing, with no projection interference.

o Operational Characteristics

- Interactivity - no dynamic ability to select digital data except by creating separate plots. Interactivity with graphic sources is same as other concepts employing image projection techniques.
- Processes - time required for plotting of digital data and time required for preparing microforms for projection system would degrade throughput.

(6) <u>Results</u>

This section presents a summary of the major trade-offs for each of the design concepts presented above. The evaluation factors included the following:

- o Functional Capabilities

  Source Coverage Analysis Function
  Comparative Source Content Analysis Function (most critical)
  Source Content Extraction

- o Operational Characteristics

  Degree of interactivity provided
  Complexity and number of required process steps
  Time-consuming processes
  Human Factors

- o Development Factors

  Technical risk involved
  Cost considerations
  Compatability with Current Design Concept

Depending on the exact set of trade-off elements used and their relative weighting, various answers could be derived as to which design approach is best. A trade-off model (Figure IV-13) was developed. The resulting decision by PRC and RADC was to pursue the definition and incorporation of Concept 5 - Digital Plot and Image Projection. Concept 3 was viewed as significantly more complex from a display hardware aspect and Concept 4 would rely on off-line plots rectification equipment. Concept 5 allows for digital transformation/rectification of extracted feature information. The concensus was that source assessment does not demand the expensive and time-consuming photo rectification processes.

	Concept 1 - Assessment Via Digital Sampling	Concept 2 - Image Scanning & Rectification	Concept 3 - Optical Trans-formation & Image Display	Concept 4 - Photo. Rec-tification & Image Dsply.	Concept 5 - Digital Plot & Image Pro-jection
FUNCTIONAL CAPABILITIES					
Source Coverage Analysis	++	++	++	++	+
Comparative Source Content Analysis	--	+	+	+	+-
Source Content Extraction	+	++	-	-	+
OPERATIONAL CHARACTERISTICS					
Degree of Interactivity	-	+	+	+	-
Complexity of Process Steps	+	--	+-	+	+-
Time-Consuming Steps	--	--	+	+-	-
Human Factors	--	-	+	+	+
DEVELOPMENT FACTORS					
Additional Hardware/Software	++	--	-	+-	+
Technical Risk	++	--	+-	+-	+
Compatability with Current Design	++	-	+	+	+

Very Good	++
Good	+
Acceptable	+-
Poor	-
Very Poor	--

Figure IV-13 Trade-off Model

b. Incorporation of SADE Concept

(1) Source Assessment/Data Extraction Description

The SADE Function is directed at allowing a cartographer to view and manipulate various combinations of graphic materials (e.g., map and film sources, data base plots, etc.). The source assessment can result in determination to use a specific source for further compilation work and/or the requirement to directly extract feature information from a source image. This type of work is normally time-consuming and requires: planning, setup, refinement of image orientation, image viewing, and feature correlation. If the user is viewing only two images for general content or change, the process and total session time is anticipated to be as little as 10 minutes. A more typical session might require several hours which includes viewing and assessing specific feature content from several source materials and extracting feature information directly from one or more of the transformed images. The feature information to be extracted would normally be used for updating/revising an existing product or providing supplementary feature information for a product compilation.

The ability to directly extract feature information from displayed and possibly transformed images will obviate the necessity to always go off-line to photographic/rectification processes prior to digitizing. Likewise the ability to directly update a compilation file with additional or revised feature information is viewed as desirable for maximum production throughput capacity.

(2) Rationale for Incorporating SADE

(a) Premises

- The hardware device to perform the required functions is estimated to cost \$140K to \$200K for development, with production model copies estimated at \$70K to \$100K.
- Utility of such devices will be varied to the extent of suggesting that different configuration options may be desirable in a production environment.

- o SADE should be incorporated within the ARCS concept in order to supplement and complement other compilation functions. The augmentation approach should not impede other compilation processes, and in fact, should result in increased cost-effectiveness.

- o Hardware development will require a significant timeframe (i.e., 1 to 2 years) and therefore will not be available until near the end of the total prototype ARCS development.

(b) Alternative Approaches

Various approaches have been considered for incorporating the SADE function into ARCS. Basically the two general approaches which were considered were as follows.

- o Autonomous Approach - design the system such that source analysis/data extraction are completely independent of other ARCS subsystems. This would result in SADE being the third subsystem within ARCS. Digitized output on a removable storage medium could be processed by the batch subsystem for commonizing with other compilation data or the output could be directly taken to the interactive subsystem.

- o Integrated with Interactive Subsystem - this approach considered: (1) the possibility of adding a new hardware component to the current interactive subsystem configuration or; (2) redesigning one of the currently defined interactive components to include source assessment and data extraction capabilities.

(c) Recommended Approach

ARCS should be designed to allow for integration of Source Assessment/Data Extraction Function with the interactive subsystem. This approach is based on the following reasons:

- The SADE function, while not necessarily interwoven with other interactive functions, can complement the interactive compilation. Assessment and resultant feature updates from graphic sources can be directly input to the interactive subsystem compilation data base. The source coverage analysis (i.e., first step in source assessment) can also be somewhat supported by display components of the interactive subsystem. For example, coverage limits of compilation sources can be maintained in the system files. Displays and plots of selected source coverage can be generated for review. Coverage plots on mylar can also be used to orient source images at the assessment device.
- Processing requirements to directly support SADE are primarily associated with data extraction (i.e., header entry and stream digitizing) and can be serviced by the master processor at the interactive subsystem. Digitizing support software will be resident at the interactive subsystem and can be designed to service the SADE Function.
- To allow for integration of SADE also allows for configuring ARCS such that SADE can also be an independent subsystem. This configuration would, of course, require minimal processor and peripheral services. This option is viewed as beneficial since different production elements may require diverse configurations and production loads and requirements may vary with time.

Three basic approaches were examined for actually adding the source assessment/data extraction function to the interactive subsystem environment. This is somewhat complicated by the fact that several configurations have been evaluated for

the interactive functions and three of those configurations are to be augmented with source assessment/data extraction and re-evaluated. The three configurations considered at this time were:

- o Refresh CRT/Graphic Digitizer
- o Upgraded Refresh CRT/Graphic Digitizer
- o Large Screen Display & Refresh CRT

The three approaches considered for adding the SADE Function were:

- o adding additional hardware devices which would totally support SADE and would constitute an additional work station;
- o augment the graphic digitizer device with source assessment components; or
- o augment the large screen display device with source assessment components.

Augmenting the large screen display device initially looked promising since the device already included optical projection and microform handling components. The vendor of the large screen device scoped the problem as a highly complex redesign of his off-the-shelf model and viewed such, as impractical. Additionally, the display of source images would be on a vertical viewing plane and thus much less amenable to graphic mylar overlaying and data extraction. Comparison with digital feature information could be accomplished very easily via the large screen plot capability.

The possibility of combining the source assessment function with the interactive compilation work station is certainly feasible from a hardware viewpoint. A digitizer is already required at the station. Adding the source assessment components to the digitizer would significantly increase the station cost. Increased functional capability would somewhat offset the

cost. A major conflict with this approach is that by collocating the SADE and interactive compilation functions use of either of the functions will prevent concurrent exploitation of the other. Based on estimates of the hardware costs for the source assessment/data extraction device and interactive compilation devices the combined station would roughly double in cost. Based on these premises, collocating the functions could result in production bottlenecks and would definitely result in the station being less cost effective. A user's need to intermix the two functions although is a valid requirement for minor graphic revision work and certain portions of the compilation.

The best approach to solve this dilemma is to design the interactive subsystem with separate work stations (i.e., SADE and interactive compilation) which can be re-configured to combine certain devices normally resident with the other station.

V. ALTERNATIVE CONFIGURATIONS AND TRADE-OFFS

Based on the evaluation of the preliminary configurations (Section IV-C-3) and the results of the Source Assessment/Data Extraction Analysis (Section IV-C-4) the next step was to incorporate the SADE Station into the three most promising configurations.

The three alternative configurations are presented below for consideration in design of the interactive subsystem portion of ARCS. Since the SADE function was determined to require a separate work station, inclusion of the function represents a constant augmentation to the three configurations. A summary of the trade-off factors is presented in Section V-D.

A. Configuration 1 - Refresh CRT

1. Distinguishing Characteristics

The major attribute of this configuration is that two primary work station types (i.e., interactive graphic display and source assessment device) are employed for performance of compilation activities. Major characteristics include: highly dynamic and flexible interactive capabilities of the CRT device; limitations to the amount of feature information which can be displayed at one time; and hardware upgrade potential in areas of display capacity, variation of spot sizes, and finer addressable resolutions.

This configuration will rely heavily upon graphic plots to present symbolized and/or line center representations of the total product area. These plots will provide an off-line vehicle for compilation planning and annotation of actions to be performed at the compilation station. Due to the importance of quality plots to this configuration concept, consideration should be given to techniques for generating plots in the most responsive manner.

2. **Major Cartographic Components and Characteristics**

Interactive Compilation Station

- o Graphic Refresh CRT
- o Graphic Digitizer and Cursor
- o Alphanumeric CRT and Keyboard
- o Function Keyboard

Source Assessment Station

- o Assessment/Data Extraction Device
- o Alphanumeric CRT and Keyboard
- o Function Keyboard

a. Graphic Refresh CRT

o Accuracy/Precision

- Addressable Resolution: $\leq$ .005"
- Spot Size: $\leq$ .012"
- Vector Size: $\leq$ .005"
- Relative Positioning Accuracy $\pm$.005"

o Image Size

- Minimum: 10" x 10"

o Display Volume

- $\geq$25,000 vectors at 30 frames per second (e.g., 250 features at 1 inch/feature and 100 vectors/inch)

o Brightness

- $\geq$25 foot lamberts

o Line Differentiation

- Minimum: 6 levels (via hardware or software techniques)

In summary, the refresh CRT could display approximately 330 inches of feature information assuming an average vector size of 10 mils and 16.5K words of storage at 2 vectors per word. At a density of 20 inches of feature data per square inch, a 4" x 4" display could be generated. The same data magnified by 2X could fill an 8" x 8" display area, magnified by 3X could more than fill 10" x 10" display area.

b. <u>Graphic Digitizer</u>

- <u>Table Characteristics</u>
  $\geq$ 42" x 58" usable digitization area (backlighting desirable)
- <u>Resolution</u> $\leq$ .002"
- <u>Overall Accuracy</u> $\leq \pm .005$"
- <u>Repeatability</u> $\leq$ .002"
- <u>Cursor</u>
  - Free-moving for pointing and tracing
  - Minimum no. of control buttons = 5 (e.g., FIND, POINT, TRACE, EDIT, etc.)
- <u>Mechanical Adjustments</u>
  - Tilt
  - Height
- <u>Physical Structure</u>
  Capable of providing a separate gantry above the table for placement of the refresh CRT and A/N CRT.
- <u>Interface</u>
  Interface control unit for integration with main processor.

c. <u>Alphanumeric CRT & Keyboard</u>

- <u>Keyboard</u>
  - Standard alphanumeric
  - Detachable

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CARTOGRAPHIC COMPILATION STUDY. VOLUME I. SYSTEM REQUIREMENTS A--ETC(U)
OCT 77 M L TAYLOR, R P O'CONNOR F30602-73-C-0036

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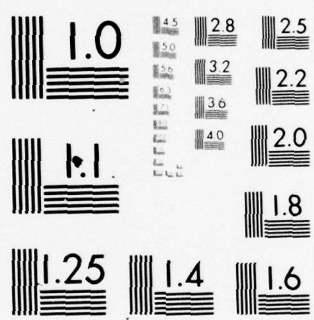
ADA048 220



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

o **Display Volume**

- Minimum 20 lines at 60 characters/line
- Character height: .125" - .25"

o **Writing Speed**

Full screen ≤ 1 second

o **Required Features**

- ASCII code
- cursor control in all directions including home and return
- display symbols ≥ 96
- addressable cursor
- cursor blinking
- line or character insert and delete
- buffering (line)

d. **Source Assessment/Data Extraction Device**

o **Table Surface and Viewing Plane Characteristics**

- Minimum (20" x 30") usable work area for digitization, viewing of imagery and placement of graphic materials.
- Projected image plane must be coincident with the top side of the table surface to minimize parallax.
- Placement of transparent graphics on the table surface nor user movements above the table should restrict or interfere with the projected image display.
- The medium of the viewing surface should minimize the diffusion of the projected image so that a clear, sharp image is maintained.

- The graphics table must provide coordinate digitizing in a manner compatible with the other graphic digitizer component (i.e., same data format, accuracy, resolution, etc.)

o Graphic Source Formats

- Positive Litho — 20" x 30" Maps/Charts/Plots (10" x 14" should be viewable) option for handling (mounting) large formats would be desirable.

- Positive Film (Frame and Panoramic Format) — 9" x (variable length)
9" x 18"
6" x (variable length)

o Graphic Display Characteristics

- Simultaneous display of at least two independently projected images.
- Each source image display area should be no less than (10" x 14") and may be manually repositioned anywhere within the usable table surface area.
- Display only segments (windows) from either of the source graphics.
- "Flip" either image on or off.
- Visually distinguish each separate source image (e.g., highlight each image with a different tint, color, or intensity level).
- Permit true color images.
- Permit color filtration for suppressing major colors/tints from the viewed image.
- Independent focusing of each source image.

o Display Accuracy

- Positional Accuracy of the graphic image identical to the true scale hard copy version of the graphic $\pm$.002").

o Image Registration

- Each graphic display mechanism must provide for independent positioning of its projected image.

- The following image transforms may be applied independently to both source images:
  - -- 2 axes scaling (anamorphic transformation along either orthogonal axis). Axes orientation is selectable and independent scaling $\pm$ 10%.
  - -- Scaling range for each source image (.2 to 2X).
  - -- Translation (to allow for overlap of images at any position within the display area).
  - -- Rotation (0° to 360°)

3. Trade-Offs

a. Functional/Operational Characteristics

The refresh CRT configuration is highly responsive to the functional requirements of the station because of its inherent display dynamics and speed. All displays, once the display file is generated, will be instantaneous. Generation of the display file will be comparable with other display systems, as time will be dependent on fetch time, special processing and formatting time, and time to pass the data to display memory. Operationally the station sacrifices some throughput potential and raises a human factors problem because of limitations to the display capacity and associated display area (maximum 10" x 10" display and in extremely dense areas a 4" x 4" display),thus requiring more display interaction to cover a complete product area. Except for general comprehension while starting to work an area and near the end for, again, a comprehensive impression of the end product, this station configuration satisfies the overall area presentations via graphic plots.

A major constraint of all immediately available refresh CRT's is the capability to display cartographic quality at 1X. The above configuration requires at least 2X magnification to maintain cartographic precision. The major contributing factors to this deficiency are addressability and spot size.

b. Station Costs

The primary hardware costs, excluding master processor and associated peripherals, for this station would be for the refresh CRT and associated miniprocessor, graphic digitizer table, alphanumeric display device and source assessment/data extraction device. Representative costs for these devices are as follows:

Refresh CRT Station

-	Refresh CRT with 32K Memory, Interface Unit, Cursor Control Device, and other associated display support options.	$45,000
-	Graphic Digitizer Table with Interface Unit and Cursor Devices.	$18,000
-	Alphanumeric CRT and Keyboard	$ 3,000
		$66,000

Source Assessment Station

-	Source Assessment/Data Extraction Device, Interface Unit, Cursors.	$100,000*
-	Alphanumeric CRT and Keyboard	3,000
		$103,000

Total cost of cartographic devices for Configuration 2 is $169,000.

c. Technical Risks

All items proposed for this configuration are within the state-of-the-art and have been demonstrated individually in related application areas. The only major risk area is associated with special hardware development for the source assessment devices.

*Estimated cost for production models based on hardware vendor estimates for development of experimental model.

B. Configuration 2 - Upgraded Refresh CRT

1. Distinguishing Characteristics

This configuration is identical to Configuration 1 with the exception that the Refresh CRT would be specially developed. Specific hardware improvements would include the following:

Addressability	4K x 4K
Spot Sizes	Variable spot sizes (e.g., 4, 8, and 12 mils)
Display Capacity	64,000 short vectors
Display Speed	≈ 500 ns/short vector

2. Major Components and Characteristics

Same as Configuration 1 except for Refresh CRT characteristics for addressability, spot sizes, and display capacity.

3. Trade-Offs

a. Functional/Operational Characteristics

This display device will permit the cartographer to view more feature information at higher precision and improved line quality. These advantages would allow the user to perform significantly more interactive processes using 1X displays. This fact would improve production throughput and generally improve human factors because fewer displays would be required and user confidence would be higher.

b. Station Costs

Same as Configuration 1 except for the additional cost for engineering development and additional memory which would total to ≈ $90,000 for the initial model. Subsequent models are estimated at approximately $65,000 or $20,000 more than the standard refresh CRT.

Refresh CRT Station

-	Upgraded Refresh CRT with 48K Memory, Interface Unit, Cursor Control Device, and other associated display support options.	$65,000
-	Graphic Digitizer Table with Interface Unit & Cursor Devices.	$18,000
-	Alphanumeric Display CRT & Keyboard	$ 3,000
		$86,000

The Source Assessment Station would cost the same as for Configuration 1 and therefore the estimated cost for Configuration 2 (Production Models) is $189,000

c. Technical Risks

Same as Configuration 1, with the additional risk associated with engineering and development for the enhanced refresh CRT.

C. Configuration 3 - Large Screen Display and Refresh CRT

1. Distinguishing Characteristics

This configuration would include three work stations: source assessment/data extraction station, interactive compilation station, and large screen display station. The large screen display provides a large scale, high resolution display. The primary drawback with the large screen display device is the lack of drawing speed which in turn negatively affects display dynamicism. The refresh CRT, on the other hand, has a high degree of dynamicism with limited resolution and data capacity. The integration of these two devices into a single system will provide large scale, high resolution, and good interactive display capabilities. This will be accomplished by performing operations which require a high degree of interactivity on the refresh CRT (such operations would primarily involve feature adjustments) while using the large screen display to present the working data base.

The refresh CRT will display only the local area which affects the particular feature or features being modified. The modified area can then be integrated into the large screen display upon operator request. Often it will be possible for graphic manipulations to continue on the refresh CRT while the large screen plot is being updated, thus reducing wait times induced by the large screen device.

Some operations which do not require a high degree of interactivity will be performed on the large screen display. Deletion is an excellent example of a large screen display oriented operation. Features could be selected for deletion using the large screen display cursor and track ball or the digitizing cursor. An edit character or

some other indicator would be generated along the feature on the refresh graphics of the large screen display to indicate deleted features. The operator would continue selecting features for deletion until he wished to view the updated file at which time he would call for a new large screen display.

2. Major Components and Characteristics

Same as Configuration 1 with the addition of a large screen display station.

Large Screen Display Device

- Accuracy/Precision

Addressable resolution	$\leq$ .002"
Minimum spot size	$\leq$ .008"
Vector size (minimum)	$\leq$ .002"
Repeatability	$\leq$ .05%
Vector Size Diversity	.002" to .010"

- Image Size

Minimum:	19" x 27"
Optimal:	37" x 53"

- Maximum Display Volume

Minimum screen (19" x 27")	$\geq$ 20,000 inches (5,000,000 short vectors)

- Character/Symbol Generation

Variety:	60 characters (compatible with A/N CRT keyboard set)

- Line Differentiation

Minimum:	6 levels
Recommended: (via hardware or software techniques)	3 Line Weights: 8, 12, 16 mils; 3 Symbol Types: dash, tick, dot

- o **Display Speeds**

  10,000 short vectors/second (4 to 10-mil vectors)

- o **Dynamism**

  Refresh graphic/cursor superpositioning

  Write/erase characters/point symbols - 250 minimum

- o **Cursor Control**

  Track ball and automatic cursor tracking

- o **Alphanumeric Keyboard**

  Standard alphanumeric

- o **Function Keyboard**

  Minimum number of keys = 16

- o **Hardcopy Output**

  Diazo microfilm copy capability

3. Trade-Offs

a. Functional/Operational Characteristics

Configuration 3 presents the most nearly optimal configuration to perform the compilation task. Any weaknesses of one station are supported by the strengths of the other. There are, however, three major drawbacks in the hybrid configuration: 1) human factors, 2) cost, and 3) software overhead.

The human factors are negatively affected by the introduction of yet another graphic viewing plane. The physical size of the large screen display prevents it from being physically collocated with either of the other stations. Therefore the user's attention must be directed away from either the digitizer or the refresh CRT to determine the effect of his action on the large screen display. This problem may prove to be inconsequential but certainly is a potential drawback if the user must spend a good deal of his time glancing back and forth among devices.

b. Station Costs

The hardware cost per station of the large screen display and Refresh CRT Hydrid Configuration can be broken down by device.

The hardware cost for cartographic components are similar to Configuration 1 plus the large screen device costs.

Refresh CRT Station	$66,000
Large Screen Display Station	$125,000
Source Assessment/Data Extraction Station	$103,000
	$294,000

It should be noted that the large screen display requires an associated processor. It is expected that a host processor will be capable of providing intelligence to the large screen display without an additional dedicated processor. The refresh CRT price does include a processor. It can be seen that the hybrid system is significantly more expensive than either of the processing configurations. This cost reflects some overlap in the hardware functions of both the large screen display and the refresh CRT. The hybrid configuration will, however, be most responsive to the compilation problem and more flexible in its use.

The hybrid configuration will require additional software and hardware to support two graphic displays. Analysis of the display formats will determine whether multiple formats will have to be retained or whether a common format will service both displays and be converted before transmission to the device. In either case additional software is required for data base support or conversion. The duplicity of control between devices will also increase the required software.

c. Technical Risk

Technical risk is slightly higher due to relatively new large screen display technology. Additional software complexity must also be considered at master processor.

D. Summary of Trade-Off Factors

A consideration for the comparative costs and throughput analysis is that Configurations 1 and 2 do not provide a device for hardcopy proof quality plotting, whereas Configuration 3 provides a high quality microfilm plot, which can be quickly enlarged for full scale viewing, proofing, and intermediate product usage. The assumption is that Configurations 1 and 2 would require access to off-line proof quality plotters. Inclusion of such a plotter as part of ARCS would require approximately $40,000 to $50,000.

Lastly, Configuration 3 actually provides for concurrent use of three cartographic work stations, serviced by a single master processor for standard control services (e.g., file I/O, data retrieval, etc.) while each work station provides a unique set of specialized functions, the combined functions of the subsystem represents a powerful interactive cartographic capability.

The following summarizes the relative merits of the three current alternatives against 8 trade-off elements. The throughput capacity was viewed as a major factor in configuration selection and therefore is presented in detail in Section VI.

- Functional Capabilities

  Facilities which allow for or provide all defined functional requirements: source assessment, data extraction, interactive feature manipulation and generalization, graphic display and plotting, and alphanumeric text placement.

  (1) Refresh CRT - Lacks size and capacity in display capabilities.

  (2) Upgraded Refresh CRT - Minor lack of capacity for high density areas, plus a limited display area.

  (3) Large Screen and Refresh CRT - Supports all required capabilities.

- Operational Characteristics

  Human factors, display speed, display capacity, quality of displays, interactiveness.

  (1) Refresh CRT - Very fast, good interactive capabilities, reasonable display interpretation characteristics, good integration potential with user environment (i.e., digitizer table).

  (2) Upgraded Refresh CRT - Improved display interpretation with multiple line weights, increased display capacity, and quality displays at 1X.

  (3) Large Screen and Refresh CRT - Large screen is generally slow, provides interactive dynamics for only low volume data, high quality and large area display. Refresh CRT provides all benefits noted above for (1). Coordination of Graphic CRT and Large Screen Display by the user will be critical operational factor.

- Cost

  Hardware cost per interactive station excluding cost of host computer system (hardware). The shared cost for the host computer and associated standard peripherals are considered equal for each configuration.

  (1) Refresh CRT Configuration

Refresh CRT Station	$ 66,000
Source Assessment Station	$103,000*
	$169,000
Optional Proof Plotter Station	$ 40,000
	$209,000

(2) Upgraded Refresh CRT Configuration

Refresh CRT Station	$ 86,000**
Source Assessment Station	$103,000*
	$189,000
Optional Proof Plotter Station	$ 40,000
	$229,000

(3) Large Screen & Refresh CRT Configuration

Refresh CRT Station	$ 66,000
Source Assessment Station	$103,000*
Large Screen Display Station	$125,000
	$294,000

*Additional $50,000 to $100,000 for source assessment hardware development.

**Additional $20,000 for refresh CRT hardware development.

- o <u>Expandability</u>

  Possible multi-station expansion, as well as, single station configurations for special applications and conformance to production workloads. Incorporation of advanced (upgraded) hardware.

  (1) Refresh CRT - Excellent upgrade prospects, good multi-station potential.

  (2) Upgraded Refresh CRT - Good multi-station potential.

  (3) Large Screen and Refresh CRT - Excellent functional expansion and hardware upgrade options for Refresh CRT. Possible variations to production configuration is especially attractive.

o **Throughput Capacity**

Display speed. Scale of Quality Display (1X, 2X, etc.) - worse than 1X lessens throughput potential. Dynamics of interactive processes. Responsiveness to all critical functional processes.

(1) Refresh CRT - Fair to good (limited display area and capacity, although meaningful in both categories), excellent response speed and dynamics.

(2) Upgraded Refresh CRT - Good (higher capacity and more useful for 1X displays).

(3) Large Screen and Refresh CRT - Good to excellent (proper use of large screen and refresh CRT will provide effective throughput).

o **Technical Risk**

Level of risk involved with design and development which requires special or untested hardware devices.

(1) Refresh CRT - Equipment has been proven in cartographic applications.

(2) Upgraded Refresh CRT - Minor new development, although stated as within state-of-the-art.

(3) Large Screen and Refresh CRT - Mostly proven hardware devices. Multiple display devices offers possible options for achievement of required functions.

o **Application Flexibility**

Adaptability of system to support new applications or support other production processes.

(1) Refresh CRT - Good prospects (very dynamic, good capacity).

(2) Upgraded Refresh CRT - Very good prospects (precision, line weights, etc.).

(3) Large Screen and Refresh CRT - Very good potential for adding cartographic applications and good flexibility in performance of required functions.

o Development Complexities

Difficulty and extent of special software and hardware required.

(1) Refresh CRT - Excellent experience with refresh CRT's in cartographic environment.

(2) Upgraded Refresh CRT - Some new hardware features (small impact on software).

(3) Large Screen and Refresh CRT - More complex because of dual display interfacing and software requirements to support multiple display formats.

VI. PRODUCTION THROUGHPUT ANALYSIS

A. Introduction

The goal of the analysis was to compare the throughput potential of the three most promising configurations and relate the projected productivity to current manual compilation and revision production standards at DMAAC. The general approach taken was to develop a production throughput model of the advanced system. The model provided a flexible tool to compare the three alternative configurations, as well as, project the potential throughput capacity of an advanced system using various product types and production situations. Manual production figures were extracted from DMAAC standards for comparson with the potential capacity of the advanced system.

B. Advanced System Model Development

This section presents the production model used for determining the throughput potential of the advanced system. The production steps, depicting the advanced system flow, are based on prior project analysis.

1. <u>Production Flow and Process Steps</u>

The compilation and revision of graphic products was broken into 14 major production steps. The production steps, defined below, provide the basis for projecting man and equipment timing parameters. A flow diagram illustrating the sequencing of the production steps is presented in Figure VI-1.

(10) Job Planning

(20) Data Bank Accessing

(30) Source Assessment

- (31) Build Compilation Reference Frame
- (32) Source Coverage Analysis
- (33) Graphic Assessment

(40) Data Extraction

(50) Compilation Batch Processing

(60) Interactive Graphic Revision and Compilation

- (61) Session Setup
- (62) Graphic Display
- (63) Interactive Generalization
- (64) Interactive Feature Manipulation
- (65) Alphanumeric Text Assignment
- (66) Session Wrap-Up

(70) Compilation Proofing and Review

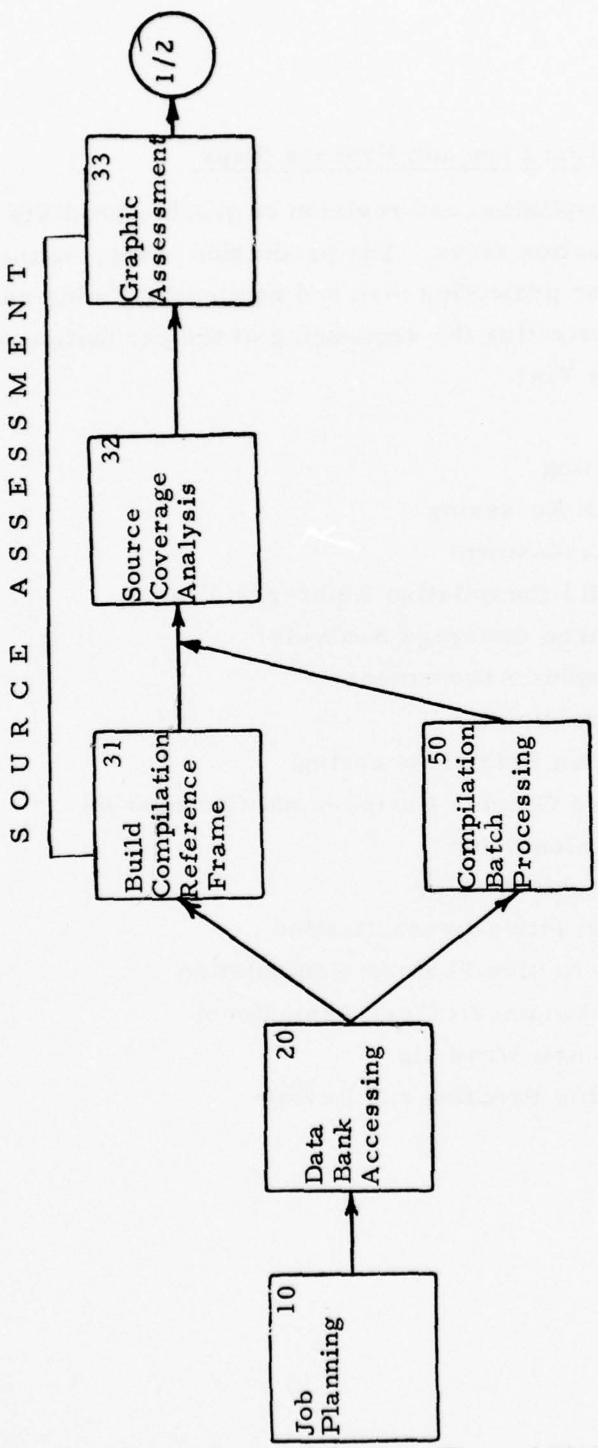


Figure VI-1 Advanced System Flow of Major Steps (Page 1 of 2)

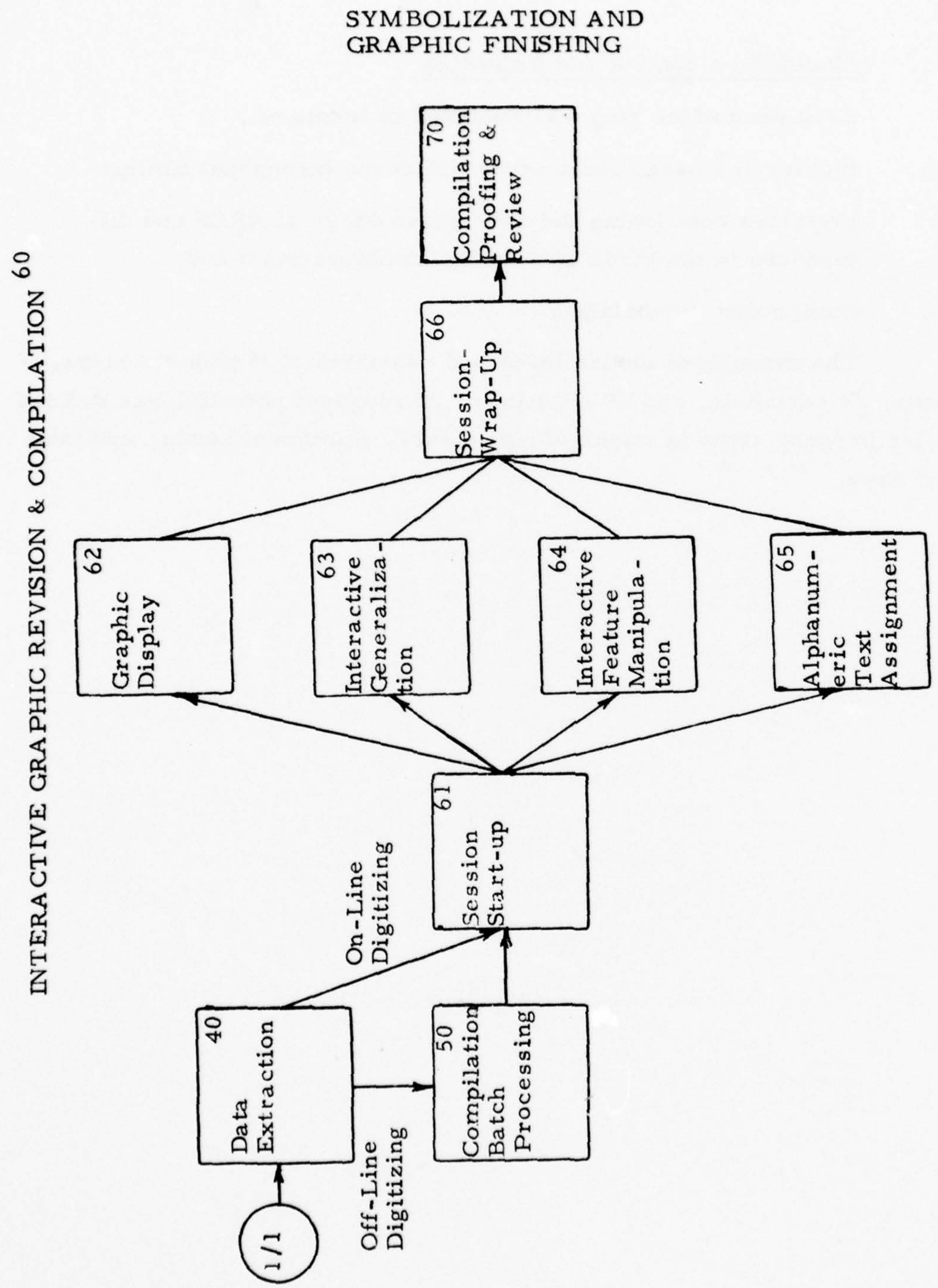


Figure 1 Advanced System Flow of Major Steps (Page 2 of 2)

2. Model Development and Definition

Each production step was analyzed in terms of:

- factors and parameters which affect the throughput timing;
- premises concerning the anticipated usage of ARCS and differences in the three alternative configurations; and
- math model formulation

The throughput model developed consisted of 14 process steps, 47 constants, 24 variables, and 39 equations. Throughput potential was defined for major process steps in terms of man-hours, equipment hours, and total elapsed days.

a. Job Planning (10)

- Purpose

  This step represents general planning for the complete compilation or revision job. Source availability will be examined and man and equipment schedules will be developed.

- Timing Parameters

  - Type of job - revision or compilation
  - Product - small or large format

- Premises

  No difference due to alternative configurations.

- Math Model

  - *Constants*

    W_T = waiting time between production steps (man-hours)

    J_S = job planning standard (man-hours)

  - *Variables*

    F_t = format type (1=small; 2=large)

    J_f = job type factor (compilation=1.0; revision=.5)

  - Man-Times

    $T_{10m} = F_t \times J_f \times J_s$

  - Equipment Time

    $T_{10e} = 0$

  - Total Elapsed Time

    $T_{10t} = T_{runc} \left| \frac{T_{10m}}{8} + .5 \right| + W_T$

b. Data Bank Accessing (20)

o **Purpose**

This step will consist of collecting all information pertinent to this job. Digital and graphic source information is included. This step can be compared with the current step of collecting all information to compile a control base manuscript.

o **Timing Parameters**

- No. of source digital data files.
- Volume of data per file to be retrieved.
- Setup time per job.
- Wait time for turnaround.
- No. of graphic sources to be retrieved.

o **Premises**

- The job will be supported by a variable amount of existing digital source data and graphic sources.
- Data volume is based on an overage of final product data (e.g., 6000 inches final for product will require 9000 source inches).
- Setup time will be required to prepare request form and identify retrieval parameters.
- Wait time is required for all support functions (e.g., central processor, library services, etc.)
- Digital source retrieval and formatting will require processor time.
- Revision jobs will require significantly less time than required for comp./recomp. jobs.
- No alternative configuration impact, although future on-line data link to digital data base could improve turnaround time.

o **Math Model**

- Constants

  Q_d = query time for digital sources index (man-hours)

  Q_g = query time for graphic sources index (man-hours)

  S_d = analyze summary and request digital data (man-hours)

S_g = analyze summary and request graphics (man-hours)
R_d = retrieval time for digital source tape (man-hours)
R_g = retrieval time for graphic source (man-hours)
F_d = time to format digital tape copy (hours)

- Variables

N_g = number of graphic sources
N_d = number of digital sources

- Turnaround Waiting Times for Digital and Graphic Services

$$W_d = \text{trunc} \left| \frac{N_d (R_d + F_d)}{8} + .5 \right| \quad \text{(digital)}$$

$$W_g = \text{trunc} \left| \frac{N_g R_g}{8} + .5 \right| \quad \text{(graphic)}$$

- Man-Time

$$T_{20m} = Q_d + Q_g + S_d + S_g$$

- Equipment Time

$$T_{20e} = N_d \times F_d$$

- Total Elapsed Time

$$T_{20t} = \text{trunc} \left| \frac{T_{20m}}{8} + .5 \right| + \max (W_d, W_g) + W_T$$

c. Source Assessment (30)

(1) Define Compilation Reference Frame (31)

- Purpose

  This step will include: identification of the projection parameters for the compilation reference frame, loading the data into the interactive subsystem, and verifying the computed intersects.

- Timing Parameters
  - Data entry time for projection and boundary parameters.
  - Reference frame computations and file creation.
  - Verification of reference frame.

- Premises
  - Reference frame data is readily available.
  - Time to perform this step will be relatively constant and independent of complexity of compilation job.
  - No significant impact because of alternative configurations.

(2) <u>Source Coverage Analysis (32)</u>

- o <u>Purpose</u>

  This step will result in the user identifying and assessing the coverage limits/overlaps of all sources considered for the job. The source limits and pertinent identification will be entered for each source. Coverages for selected sources will be displayed for user perusal and planning.

- o <u>Timing Parameters</u>
  - Number of sources (average varies per product type).
  - Data entry time for each source.
  - Coverage display time.
  - Analysis time.

- o <u>Premises</u>
  - Number of graphic sources will vary per job and product type (e.g., large vs. small format)
  - Data entry time for each source will be relatively constant.
  - User will selectively display source coverages and perusal time will vary.
  - Large Screen Display capability in Configuration 3 is useful for area coverage analysis and final review.

(3) Graphic Assessment (33)

- Purpose

  To compositely display, manipulate and view multiple graphic sources. The user will identify update requirements and determine the best means to further exploit selected sources. The user can directly extract feature information and/or identify feature types and sources requiring digitization.

- Timing Parameters

  - Digital data plotting of compilation reference frame, source coverage, and digital feature data.
  - Number of graphic sources.
  - Setup time per source.
  - Review time per source.

- Premises

  - Minimum of 2 plots will be required.
  - Review and assessment time can greatly vary per job.
  - Feature extraction can occur during assessment and is accounted for under Data Extraction (40).
  - Configuration 1 and 2 will require hardcopy plotter services.

(4) Math Model (Combined Source Assessment Steps)

- Constants:

T_{31m} = man-time required to define compilation reference frame (man-hours).

T_{31e} = equipment time required to support definition of compilation reference frame (hours).

E_d = source description entry time per source (man-hours).

C_d = coverage display and analysis time per source (man-hours).

P_h = plot tape handling and requesting off-line services (man-hours).

P_g = plot tape generation time (hours).

P_d = actual plotting time per plot tape (hours).

W_p = plot in-queue waiting for service time (hours).

S_s = source assessment setup time per source (man-hours).

A_r = review/assessment time per source (man-hours).

G_p = graphic source preparation

- Variables

N_p = number of digital plots required to support source assessment.

A_g = percentage of graphic sources (N_g) accepted (0-1.0).

- Man-Time for Source Coverage Analysis

$T_{32m} = (N_g + N_d) \times (E_d + C_d)$

- Equipment Time for Source Coverage Analysis

$T_{32e} = T_{32m}$

- <u>Man Time for Graphic Assessment</u>

  $T_{33m} = (1-PL) \times N_p \times P_h + (A_g \times N_g)(S_s + A_r + G_p) +$

  $PL \times (L_g + LE) \times N_p$

- <u>Equipment Time for Graphic Assessment</u>

  $T_{33e} = T_{33m} + (1 - PL) \times N_p (P_g + P_d - P_h)$

- <u>Overall Man-Time for Source Assessment</u>

  $T_{30m} = T_{31m} + T_{32m} + T_{33m}$

- <u>Overall Equipment Time for Source Assessment</u>

  $T_{30e} = T_{31e} + T_{32e} + T_{33e}$

- <u>Overall Total Elapsed Time for Source Assessment</u>

  $T_{30t} = \text{trunc} \left| \frac{\max(T_{30m}, T_{30e}) + N_p \times W_p + .5}{8} \right| + W_T$

d. Data Extraction (40)

o **Purpose**

This step consists of conventional digitizing of features from graphic sources. Digitizing is anticipated to be performed at the interactive subsystem and/or off-line digitizing system.

o **Timing Factors**

- Volume of data to be extracted.
- Digitizing rate.
- Turnaround time for off-line digitizing.

o **Premises**

- Percentage of source data requiring digitizing will vary.
- Digitizing rate is 100" per hour.
- Digitizing will normally be performed from source scales larger than the compilation scale. Example, for 1:250,000 scale compilation, source graphics might include 1:200,000 and some 1:50,000 scales. Therefore to generate 4500" of digital source at compilation scale might require digitizing of 9000" from original source. Digitizing from optically scaled source at the source assessment device can reduce the digitizing volume.
- No impact due to alternative configurations.

o **Math Model**

- **Constants**

  G_d = graphic digitizing rate (inches/hour).

  F_1 = average feature length (inches/feature).

- **Variables**

  S_c = average relative scale of graphic source to be digitized as compared to compilation reference frame.

  O = average factor which is the ratio of number of input feature inches: number of output product feature inches (1.0 - ?).

  V_p = product volume in terms of number of feature inches.

D_s = ratio of digital source available: graphic source available over the product area (0 - 1.0).

- Man-Time and Equipment Time

$$T_{40m} = T_{40e} = \frac{O \times V_p \times F_1 \; (1-D_s) \times S_c}{G_d}$$

- Total Elapsed Time

$$T_{40t} = \text{trunc} \left| \frac{T_{40m}}{8} + .5 \right| + W_T$$

e. Compilation Batch Processing (50)

o **Purpose**

This step will involve processing of digital source data which requires commonizing to conform to the compilation reference frame.

o **Timing Parameters**

- Volume of data to process.
- No. of batch jobs to setup and execute.
- Job setup time.
- Processing rate.
- Wait time for batch job turnaround.
- Job verification time.

o **Premises**

- Batch software processes are implemented on standalone computer system. If batch software was implemented on same processor as interactive subsystem, some savings could be accrued due to I/O processing and turnaround time.
- No major impact due to alternative configurations.

o **Math Model**

- Constants

  J_t = job turnaround time (hours).

  S_j = job setup time (man-hours).

  S_v = job post-process verification and review (man-hours).

  P_r = average processing rate per 1000 points (hours).

  R_d' = average resolution of data to be processed (points/inch).

- Variables

  B_j = number of batch jobs to be run.

- Man-Time

  $T_{50m} = B_j \times (S_j + S_v)$

- <u>Equipment Time</u>

$$T_{50e} = (O \times V_p \times D_s + O \times V_p \times (1-D_s) \times S_c) \times F_1 \times R_d' \times 10^{-3} \times P_r$$

- <u>Total Elapsed Time</u>

$$T_{50t} = \text{trunc}\left[\max\left\{\left(\frac{T_{50m} + T_{50e}}{8}\right), \left(\frac{B_j \times J_t}{8}\right)\right\} + .5\right] + W_T$$

f. <u>Interactive Graphic Revision and Compilation (60)</u>

(1) <u>Session Setup (61)</u>

o <u>Purpose</u>

Log-on the system for each work session; also included is input processing of digital source files.

o <u>Timing Factors</u>

- Time to sign-on.
- Time to setup input processing job.
- Input processing time.

o <u>Premises</u>

- All digital data required for the job will be input processed at least once.
- Feature data structured for interactive processing will be maintained on removable disk devices.
- No impact due to alternative configurations.

(2) Graphic Display (62)

o **Purpose**

This activity is directed at generating all graphic displays and plots required to support interactive compilation or revision functions.

o **Timing Parameters**

- No. of display and plots required.
- Volume of data per display.
- Time required to generate the graphic.
- User perusal time per graphic (excludes interactive manipulation times).

o **Premises**

- Use of large screen display will be employed for: original displays of all information available; interim displays to support interactive generalization processes, overview of resultant compilation of major feature groups, and alpha-numeric placement; and final displays for overall review.
- Large screen display will also be employed for generating hardcopy plots for off-line review and use on the graphic digitizer for referencing.
- Refresh CRT will be employed for all detailed interactive processes where intricate feature manipulation processes are involved.
- No. of required display graphics is directly dependent on size of compilation area and situations when 2X enlargements are required for detailed work.
- While time to generate each display is dependent on data point volume, the following averages are used:

Refresh CRT	15 seconds
Large Screen Display	3 minutes
Large Screen Plot	5 minutes + 10 minutes for copier/enlarger
Off-line Hardcopy Plotter	15 min. for file generation 15 min. for plotting 15 min. for tape handling 45 minutes

- Alternative Configuration Impact - the major quantitative impact is the fact that the large screen high quality display capability (Configuration 3) will be achieved via additional displays on the Refresh CRT and hardcopy plotting. The Refresh CRT will, of course, require several displays to represent a single large screen display. Using Configuration 3 (Large Screen)as the baseline, the number of large screen displays will be estimated for original displays(n_1), interim displays (n_2), and final displays (n_3). Absence of the large screen display in Configurations 1 and 2 result in additional displays and hardcopy plots being generated on the Refresh CRT and off-line plotter. Conversion of the n large screen displays to refresh displays or hardcopy plots is summarized below.

Configuration 1 (Refresh CRT)

Conversion of n large screen displays.

n_1 (Original Display)/n_2 (Interim Displays)/n_3 Final Displays

n_1 Hardcopy Plot

$n_{2/2}$ Hardcopy Plots

n_3 Hardcopy Plots

Refresh Displays
(6 per large screen
display due to display
area difference)
$n_{2/2} \times 6$ (50% will require 2X displays
for higher quality
review and detailed
line manipulations).
24 x 4 = 96 displays
$[n_{2/2} \times 6] + (4)$

Configuration 2 (Upgraded Refresh CRT)

Conversion of n large screen displays.

n_1 (Original Display)/ n_2 (Interim Displays)/n_3 Final Displays

n_1 Hardcopy Plots

$n_{2/2}$ Hardcopy Plots

n_3 Hardcopy Plots

Refresh Displays
(6 per large screen
display)
$n_{2/2} \times 6$

(3) Interactive Generalization (63)

- o Purpose

  This interactive function will allow the compiler to apply a number of generalization processes to 1 or a group of features.

- o Timing Parameters
  - Number of generalization actions.
  - Time required per action.
  - User perusal time per action.

- o Premises
  - No. of generalization actions will be based on total number of source features input to the interactive subsystem (i.e., 1 action/n features).
  - Generalization will normally be applied to a group of features.
  - The generalizations which could be performed at the Large Screen Display Station (Config. 3) will be less effective in Configurations 1 and 2. The primary reason is the limited area being viewed and generalized via the Refresh CRT. Configuration 1 will also require enlarged displays which will decrease the number of features manipulated per action.

(4) <u>Feature Manipulations (64) and Alphanumeric Text Assignment (65)</u>

- <u>Purpose</u>

  These steps consist of performing line edits and manipulation actions to individual features. The alphanumeric text assignment will consist of displaying and assigning features for input to Geo. Names Specialist.

- <u>Timing Parameters</u>
  - Number of feature actions.
  - Time required for each action, including perusal.

- <u>Premises</u>
  - Each action will include feature find, user perusal, and manipulation.
  - No major impact due to alternative configurations. Use of large screen display although would be very beneficial for text display and assignment.

(5) Session Wrap-Up (66)

- o **Purpose**

  This step consists of signing-off the system for each work session, and upon completion of a job output processing the compiled data file.

- o **Timing Parameters**

  - Time to sign-off.
  - No. of sessions.
  - Data volume to output process.

- o **Premises**

  - Interim data files will be maintained on disc devices.
  - All digital product data will be output processed at least once for passing to the next production phase.
  - No impact due to alternative configurations.

  - **Constants**

    R_c = resolution of digital data input for compilation (points/inch).

    I_r = input processing rate (hours/1000 points).

    L_n = log-on time per session (man-hours).

    S_i = setup time for input processing per file (man-hours).

    U_l = user perusal time per large screen display (man-hours).

    U_r = user perusal time per refresh CRT display (man-hours).

    L_g = average large screen display generation time (hours).

    U_p = user perusal time per hardcopy plot for graphic revision/compilation (man-hours).

    C_g = average refresh CRT display generation time (hours)

    I_g = interactive generalization processing time per action (hours)

    U_g = user perusal time per generalization action (man-hours).

F_m = feature manipulation processing time per action (hours).

U_m = user perusal time per manipulation action (man-hours).

A_p = alphanumeric text placement processing time per action (hours).

U_a = user perusal time per text placement action (man-hours).

L_f = log-off time per session (man-hours).

O_r = output processing rate (hours/1000 points).

S_o = setup time for output processing per file (man-hours).

- Variables

  C_s = number of compilation sessions.

  F_i = number of data tape files (post-batch processing) input for interactive compilation.

  LD = number of large screen displays required.

  RD = number of refresh CRT displays required.

  M_f = percentage of features requiring feature manipulation (0.0 - 1.0).

  A_f = percentage of features requiring text placement.

  HP = number of hardcopy plots to support GR&C.

  F_O = number of output tape files produced.

  F_g = average number of features each generalization action is applied against.

- Man-Time for Session Setup

  $T_{61m} = L_n \times C_s + F_i \times S_i$

- Equipment Time for Session Setup

  $T_{61e} = T_{61m} + O \times V_p \times F_1 \times R_c \times I_r \times 10^{-3}$

- Equipment Time for Graphic Display

$T_{62e} = LD \times (L_g + U_l) + RD \times (C_g + U_r) + (1-PL) \times HP \times (P_g + P_d + U_p) + PL \times HP \times (L_g + LE)$

- Man-Time for Graphic Display

$T_{62m} = T_{62e}$

- Equipment Time for Interactive Generalization

$T_{63e} = \dfrac{O \times V_p \times (I_g + U_g}{F_g}$

- Man-Time for Interactive Generalization

$T_{63m} = T_{63e}$

- Equipment for Feature Manipulation

$T_{64e} = O \times V_p \times M_f \times (F_m + U_m)$

- Man-Time for Feature Manipulation

$T_{64m} = T_{64e}$

- Equipment Time for Alphanumeric Text Placement

$T_{65e} = V_p \times A_f \times (A_p + U_a)$

- Man-Time Alphanumeric Text Placement

$T_{65m} = T_{65e}$

- Man-Time for Session Wrap-Up

$T_{66m} = C_s \times L_f + F_o \times S_o$

- Equipment Time for Session Wrap-Up

$T_{66e} = T_{66m} + F_o \times V_p \times F_l \times R_c \times O_r \times 10^{-3}$

- Overall Man-Time for Interactive Graphic Revision and Compilation

$T_{60m} = T_{61m} + T_{62m} + T_{63m} + T_{64m} + T_{65m} + T_{66m}$

- Overall Equipment Time for Interactive Graphic Revision and Compilation

$T_{60e} = T_{61e} + T_{62e} + T_{63e} + T_{64e} + T_{65e} + T_{66e}$

- <u>Total Elapsed Time for Interactive Graphic Revision and Compilation</u>

$$T_{60t} = \text{Trunc}\left| \frac{(T_{61e} + T_{62m} + T_{63m} + T_{64m} + T_{65m} + T_{66a}}{8} + .5 \right| + W_T$$

g. Compilation Proofing and Review (70)

o Purpose

This step will be directed at proofing of critical compilation processes and compiler actions and final review of the compiled graphics. Special displays, plots, and process reports will be employed.

o Timing Parameters

- Review of compilation job, processes performed, and statistical reports.
- Large screen displays (before and after comparisons).
- Hardcopy plots.
- User perusal time.

o Premises

- Proofing will be performed intermittent with graphic revision and compilation processes.
- The system will aid the reviewer during proofing, although significant time is anticipated for light table review of plots.
- Configuration 1 - large screen displays will be generated via hardcopy plotter. This represents a degradation to proofing.
- Configuration 2 - before/after proof displays will be generated on the enhanced Refresh CRT.

o Math Model

- Constants

  PD_g = large screen display for proofing review generation time (hours).

  PU_r = on-line proofing review time per large screen display (man-hours).

  LE = large screen plot enlargement time (optional) (hours).

- Variables

  PL = on-line/off-line hardcopy plotter flag (1=on-line; 0=off-line).

PR = number of hardcopy proofing plots required.

PD = number of large screen displays for on-line proofing review.

RV = off-line proofing review time (man-hours).

- <u>Equipment Time</u>

  $T_{70e} = (1-PL) \times PR \times (P_g + P_d) + PD \times (PD_g + PU_r) + PL \times PR \times (PD_g + LE)$

- <u>Man-Time</u>

  $T_{70m} = (1-PL) \times PR \times Ph + PD \times (PD_g + PU_r) + PL \times PR \times (PD_g + LE) + RV$

- <u>Total Elapsed Time</u>

  $$T_{70t} = \text{trunc}\left| \frac{(T_{70m} + (1-PL) \times PR \times (P_g + P_d) + (1-PL) \times PR \times W_p)}{8} + .5 \right| + W_T$$

3. Model Summary

The following charts summarize the variables, constants, and formulas which represent the advanced system production model.

CONSTANTS

Job Planning:	J_s - job planning standard (man-hours).
	W_T - wait time (days).
Data Base Accessing:	Q_d - query time for digital sources (man-hours).
	Q_g - query time for graphic sources (man-hours).
	S_d - analyze summary and request digital (man-hours).
	S_g - analyze summary and request graphics (man-hours).
	R_d - retrieval time for digital source tape (man-hours).
	R_g - retrieval time for graphic source (man-hours).
	F_d - time to format digital tape copy (hours).
Source Assessment:	T_{31m} - man-time required to define compilation reference frame (man-hours).
	T_{31e} - equipment time required to support definition of compilation reference frame (hours).
	P_h - plot tape handling and requesting off-line services (man-hours).
	P_g - plot tape generation time (hours).
	P_d - actual plotting time per plot tape (hours).
	W_p - plot in-queue waiting for service time (hours).
	E_d - source description entry time per source (man-hours).
	C_d - coverage display and analysis time per source (man-hours).
	G_p - graphic source preparation (man-hours).
	S_s - source assessment setup time per source (man-hours).
	A_r - review/assessment time per source (man-hours).
Data Extraction:	G_d - graphic digitizing rate (inches/hour).
	F_l - average feature length (inches/feature).

CONSTANTS
(Continued)

Batch Processing:

J_t - job turnaround time (hours).

S_j - job setup time (man-hours).

S_v - job post-process verification and review (man-hours).

P_r - average processing rate per 1000 points (hours).

R_d' - average resolution of data to be processed (points/inch).

Interactive Graphic Revision & Compilation:

R_c - resolution of digital data input for compilation (points/inch).

I_r - input processing rate (hours/1000 points).

L_n - log-on time per session (man-hours).

S_i - setup time for input processing per file (man-hours).

L_g - average large screen display generation time (hours).

U_l - user perusal time per large screen display (man-hours).

C_g - average refresh CRT display generation time (hours).

U_r - user perusal time per refresh CRT display (man-hours).

U_p - user perusal time per hardcopy plot for graphic revision/compilation (man-hours).

I_g - interactive generalization processing time per action (hours).

U_g - user perusal time per generalization action (man-hours).

F_m - feature manipulation processing time per action (hours).

U_m - user perusal time per manipulation action (man-hours).

A_p - alphanumeric text assignment processing time per action (hours).

U_a - user perusal time per text assignment action (man-hours).

L_f - log-off time per session (man-hours).

O_r - output processing rate (hours/1000 pts).

S_o - setup time for output processing per file (man-hours).

CONSTANTS
(Continued)

Compilation Proofing & Review:

PD_g - large screen display for proofing review generation time (hours).

PU_r - on-line proofing review time per large screen display (man-hours).

LE - large screen plot enlargement time (optional) (hours).

Variables

F_t	=	format type.
J_f	=	job type factor.
N_g	=	number of graphic sources.
N_d	=	number of digital sources.
N_p	=	number of digital plots required for graphic assessment.
A_g	=	percentage of graphic sources accepted following coverage analysis.
O	=	overage factor.
V_p	=	product volume (features)
D_j	=	percentage of digital source available
B_j	=	number of batch jobs for pre-graphic compilation.
C_s	=	number of compilation sessions.
F_i	=	number of data files input after batch processing.
LD	=	number of large screen displays for graphic display purposes.
RD	=	number of refresh displays for graphic display purposes.
F_g	=	number of features per generalization.
M_f	=	percentage of features requiring feature manipulation.
A_f	=	percentage of features requiring text assignment.
F_o	=	number of output product tape files.
PR	=	number of hardcopy proofing plots required.
PL	=	on-line/off-line hardcopy plotter (1=on-line; 0=off-line).
PD	=	number of large screen displays for proofing.
RV	=	off-line proofing review time.
HP	=	number of hardcopy plots to support Graphic Revision & Compilation.
S_c	=	average scale of graphic to be digitized relative to compilation reference frame.

MAN-HOURS	EQUIPMENT HOURS	TOTAL ELAPSED TIME
$t_{10m} = F_t \times J_f \times J_s$	$t_{10e} = 0$	$t_{10t} = \text{trunc}\left\vert \frac{t_{10m}}{8} + .5 \right\vert + W_T$
$t_{20m} = Q_d + Q_g + S_d + S_g$	$t_{20e} = N_d \times F_d$	$t_{20t} = \text{trunc}\left\vert \frac{t_{20m}}{8} + .5 \right\vert + \max(W_d, W_g) + WT$ WHERE: $W_d = \text{trunc}\left\vert \frac{N_d(R_d + F_d)}{8} + .5 \right\vert$ $W_g = \text{trunc}\left\vert \frac{N_g R_g}{8} + .5 \right\vert$
$t_{30m} = t_{31m} + t_{32m} + t_{33m}$ $t_{31m} = \text{constant}$ $t_{32m} = (N_g + N_d)(S_d + S_d)$ $t_{33m} = (1 - PL) N_p (P_h + P_c) + A_r N_r (S_3 + A_r + C_p) + N_p PL (L_g + LE)$	$t_{30e} = t_{31e} + t_{32e} + t_{33e}$ $t_{31e} = \text{constant}$ $t_{32e} = t_{32m}$ $t_{33e} = t_{33m} + (1 - PL) N_p (P_g + P_l - P_h)$	$t_{30t} = \text{trunc}\left\vert \frac{\max(t_{30m}, t_{30e}) + N_p W_p}{8} + .5 \right\vert + W_T$

MODEL FORMULAS
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MAN-HOURS	EQUIPMENT HOURS	TOTAL ELAPSED TIME
$t_{40m} = \frac{O \times V_p + F_\ell (1-D_s) S_c}{G_d}$	$t_{40e} = t_{40m}$	$t_{40t} = \text{trunc}\ \frac{t_{40m}}{8} + .5 + W_T$
$t_{50m} = B_j (S_j + S_v)$	$t_{50e} = (O V_p D_s + O V_p (1-D_s) S_c)$ $F_\ell R_d' P_r 10^{-3}$	$t_{50t} = \text{trunc}\left[\max\left\{\left(\frac{t_{50m} + t_{50e}}{8}\right), \left(\frac{B_j J_t}{8}\right)\right\} + .5\right] + W_T$
$t_{60m} = t_{61m} + t_{62m} + t_{63m} + t_{64m} + t_{65m} + t_{66m}$ $t_{61m} = L_n C_s + F_\ell S_c$ $t_{62m} = t_{62e}$ $t_{63m} = t_{63e}$	$T_{60e} = t_{61e} + t_{62e} + t_{63e} + t_{64e} + t_{65e} + t_{66e}$ $t_{61e} = t_{61m} + O V_p F_\ell R_c I_r 10^{-3}$ $t_{62e} = LD(L_g + U_\ell) + RD(C_g + U_r) + HP(1-PL)(P_g + P_d + U_p) + PL \times HP (L_g + LC)$ $t_{63e} = \frac{O V_p (I_g + U_g)}{F_g}$	$T_{60t} = \text{trunc}\ \left\| t_{61e} + t_{62m} + t_{63m} + t_{64m} + \frac{t_{65m} + t_{66e}}{8} + .5 \right\| + W_T$

MODEL FORMULAS
(Page 2 of 3)

MAN-HOURS	EQUIPMENT HOURS	TOTAL ELAPSED TIME
$t_{64m} = t_{64e}$	$t_{64e} = O V_p M_f (F_m + U_m)$	
$t_{65m} = t_{65e}$	$t_{65e} = V_p A_f (A_p + U_a)$	
$t_{66m} = C_s L_f + F_o S_o$	$t_{66e} = t_{66m} + F_o V_p F_l R_c O_r 10^{-3}$	
$t_{70m} = (1-PL) PR P_h + PD (PD_g + PU_r) + PLPR (PD_g + LE) + RV$	$t_{70e} = (1-PL) PR (P_g + P_d) + PD (PD_g + PU_r) + PLPR (PD_g + LE)$	$t_{70t} = \mathrm{trunc} \left\| (T_{70m} + (1-PL) PR (P_g + P_d) + \frac{(1-PL) PR W_p)}{8} + .5 \right\| + W_T$

MODEL FORMULAS
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C. Comparative Throughput Analysis

1. Advanced System Throughput Estimates

This section consists of applying variables to the throughput model for subsequent computations of potential throughput capacity. The production situations investigated included the following:

- Alternative Configurations/Compilation/1:250,000 Scale.
- Configuration 3/Compilation/1:250,000 Scale (varying levels of digital source available).
- Configuration 3/Revision/1:250,000 Scale.
- Configuration 3/Compilation/1:500,000 Scale.

a. Model Constants and Variables

The constants and variables employed for projecting throughput potential are of course critical to the computed results. Those values assigned are based on PRC's background with such processes and represent a best estimate. The assigned constants are summarized in Table 1. Variables are assigned separately for each production situation and are presented as such.

Constant	Value	Comments
Js	10 hrs.	Estimate for general planning, scheduling, coordinating, etc.
Wt	2 days	1 day is allowed at the start and end of each major step for review and general planning.
Qd	1 hr.	Time required to request and obtain index of available digital sources.
Qg	1 hr.	Time required to request and obtain index of available graphic sources.
Sd	2 hrs.	Review of source index summaries and request specific sources.
Sg	2 hrs.	Review of source index summaries and request specific sources.
Rd	.25 hr. (15 min)	Wait time incurred for file retrieval.
Rg	.25 hr. (15 min)	Wait time incurred for graphic retrieval. This could include photo-copying.
Fd	.5 hr. (30 min)	Equipment time to copy and possibly format digital data.
T31m	.5 hr. (30 min)	Data entry and verification time.
T31e	.33 hr. (20 min)	System time required to support T31m.
Ph	.16 hr. (10 min)	Plot tape, handling time and plotter service request time.
Pg	.25 hr. (15 min)	Equipment time to generate plot tape.
Pd	.25 hr. (15 min)	Hardcopy plot time (per plot).
Wp	.33 hr. (20 min)	Wait time incurred per plot.
Ed	.16 hr. (10 min)	Source description/coverage data entry time.
Cd	.16 hr. (10 min)	Time to display and analyze source coverages (per source).
Ss	.083 hr. (5 min)	Time to set-up each graphic source for viewing.
Ar	.42 hr. (25 min)	Review and assessment time (per source).

Table 1 - Assigned Constants (Page 1 of 3)

Constant	Value	Comments
Gp	.16 hr. (10 min)	Time to prepare and mount graphic source.
Gd	100"/hr.	Average digitizing rate.
Fe	1"/feature	Average feature length.
Jt	8 hrs.	Wait time for turnaround of batch jobs.
Sj	.5 hr. (30 min)	Time required to set-up batch jobs.
Sv	.5 hr.	Time allotted for review and verification of batch job.
Pr	.00056 hr/ 1000 pts. (2 sec.)	Based on processing rate encountered for similar processes.
Rd	250 pts. / inch	Average points per inch processed (this includes data reduction during batch run).
Rc	200 pts. / inch	Average points per inch input to interactive subsystem.
Ir	.000695 hr/ 1000 pts	Rate for input processing and file structuring.
Ln	.083 hr. (5 min)	Time to log-on for system wage.
Si	.16 hr. (10 min)	Set-up time for input processing (per file)
Ue	.16 hr. (10 min)	Time allotted for general perusal time by user per large screen display.
Lg	.05 hr. (3 min)	Average (high) time for display generation of 1000 to 5000 features.
Cg	.0042 hr. (15 sec.)	Average (high) time for display generation of 100 to 250 features.
Up	.16 hr. (10 min)	Time allotted for user perusal of hardcopy plots for graphic revision/ compilation.
Ig	.0167 hr. (1 min)	Time allotted for performing interactive generalization action.
Ug	.033 hr. (2 min)	Average user perusal time to verify generalization results.

Table 1 - Assigned Constants (Page 2 of 3)

Constant	Value	Comments
Fm	.0083 hr. (30 sec)	Time allotted for performing feature manipulation action.
Um	.0083 hr. (30 sec)	Average user perusal time to verify results of feature manipulation.
Ap	.00415 hr. (15 sec)	Time allotted to assign feature for naming.
Ua	.00415 hr. (15 sec)	Average user perusal time for verification.
Lf	.083 hr. (30 sec)	Time to log-off at system.
Or	.00028 hr./ 1000 pt.	Rate for output processing of selected feature data to tape file.
So	.16 hr. (10 min)	Set-up time to define output processing parameters.
PDg	.0833 hr. (5 min)	Average (high) time required to generate proof displays on large screen.
PUr	.167 hr. (10 min)	Time allotted for user perusal time of proof displays.
LE	.167 hr. (10 min)	Time to produce enlarged copy of film plots.
Ur	.033 hr. (2 min)	Time allotted for user perusal per refresh display.

Table 1 - Assigned Constants (Page 3 of 3)

b. Alternative Configurations

This section presents a basis for projecting the potential throughput capabilities of three alternative configurations:

Refresh CRT Configuration (1)
Upgraded Refresh CRT Configuration (2)
Large Screen & Refresh CRT Configuration (3)

Production steps and associated estimates were primarily based on compilation of a small format graphic employing the Large Screen and Refresh CRT Configuration. Differences due to revision jobs, large format graphics, and the other 2 configurations are identified as appropriate, and allowed for in the math model.

The three alternative configurations are compared in this section in terms of throughput timings. Estimates were applied to the set of variables (see Table 2). The type of compilation job consisted of a 1:250, 000 scale graphic. Applying the constants and variables resulted in compilations for each individual step (presented in Table 3) and are summarized below.

	Man-Hours (m)	Equipment Hours (e)	Work Days	Calendar Days*
Configuration (3)	293.48	250.79	58	83
Configuration (2)	337.43	295.77	65	91
Configuration (1)	385.87	343.21	70	98

The primary differences in the throughput projections for the three configurations are based on differences in display capabilities. High quality, full format displays and plots can be generated by the large screen device. Absence of the large screen device results in significantly more refresh CRT displays and/or hard copy off-line plots being required. The smaller refresh CRT displays and hard copy plotting also results in increased discontinuity of feature viewing and interactive processing. These factors are illustrated by comparing the computed values for only the interactive graphic revision and compilation steps (61-66).

*Calendar days is based on 5 work shifts per 7 days.

Variables	Configuration 3	Configuration 2	Configuration 1	Rationale
Ft	1	1	1	Small format factor.
Jf	1	1	1	Factor used for compilation type jobs.
Ng	23	23	23	Assumed 50% digital source available (Standard 45 graphics).
Nd	10	10	10	Digital source is maintained on 10 files.
Np	10	10	10	Minimum 1 plot per digital source file.
Ag	.7	.7	.7	70% of graphic sources were selected.
O	1.5	1.5	1.5	Overage of information will be compiled for final selection.
Vp	6000	6000	6000	Medium density JOG 1:250,000 contains 6000 features.
Ds	.5	.5	.5	Assumed 50% digital source available.
Bj	6	6	6	Six batch jobs are required for digital files.
Cs	15	19	25	Computed based on time required for steps 6- - 66 (8 hrs/session).
Fi	6	6	6	One file resulted from each batch job.
LD	20	0	0	Assumed 1 original/16 interim compilation/3 final.
RD	60	108	204	More refresh displays are required in absence of large screen (see
Fg	20	10	5	Generalization actions are applied to multiple features/smaller area/less quantity.
Mf	.5	.5	.5	50% of digital features will require individual manipulations.
Af	.3	.3	.3	30% of final features will require alphanumeric assignments.
Fo	4	4	4	Final and review files generated.
PR	5	15	15	1 composite and 4 overlay plots/loss of large screen proof displays.
PL	1	0	0	1 on-line 1 off-line hardcopy plotting.
PD	10	0	0	Large screen displays to support proofing/hardcopy plotter employed.
RV	30	40	40	Light table review time/Loss of large screen requires additional off-line review.
HP	6	18	18	Hardcopy proof plots required for intermediate compilation review.
Sc	2.0	2.0	2.0	Graphic sources are typically larger than comp. ref. frame.

Table 2 - Assigned Variables - Alternative Configurations/ 1:250,000 Scale Compilation

JOG 1:250,000 COMPILATION (50% Digital/50% Graphic)

	Configuration 3			Configuration 2			Configuration 1		
Step	$_m$(Hr.)	$_e$(Hr.)	$_t$(Days)	$_m$(Hr.)	$_e$(Hr.)	$_t$(Days)	$_m$(Hr.)	$_e$(Hr.)	$_t$(Days)
10	10	0	3	10	0	3	10	0	3
20	6	5	4	6	5	4	6	5	4
30	23.90	23.73	5	28	34.43	6	28	34.43	6
(31)	(.5)	(.33)		(.5)	(.33)		(.5)	(.33)	
(32)	(10.56)	(10.56)		(10.56)	(10.56)		(10.56)	(10.56)	
(33)	(12.84)	(12.84)		(16.94)	(23.54)		(16.94)	(23.54)	
40	90.0	90.0	13	90.0	90.0	13	90.0	90.0	13
50	6.	1.89	8	6.	1.89	8	6.	1.89	8
60	123.83	126.42	18	155.03	156.95	22	203.47	204.39	27
(61)	(2.2)	(3.45)		(2.54)	(3.45)		(3.04)	(3.45)	
(62)	(7.73)	(7.73)		(15.90)	(15.90)		(18.61)	(18.61)	
(63)	(22.37)	(22.37)		(44.73)	(44.73)		(89.46)	(89.46)	
(64)	(74.7)	(74.7)		(74.7)	(74.7)		(74.7)	(74.7)	
(65)	(14.94)	(14.94)		(14.94)	(14.94)		(14.94)	(14.94)	
(66)	(1.89)	(3.23)		(2.22)	(3.23)		(2.72)	(3.23)	
70	33.75	3.75	7	42.4	7.5	9	42.4	7.5	9
TOTALS	293.48	250.79	58	337.43	295.77	65	385.87	343.21	70

Table 3 - Throughput Results-Alternative Configurations/1:250,000 Scale Compilation

	Man-Hours (m)	Equipment Hours (e)	Work Days	Calendar Days*
Configuration(3)	123.83	126.42	18	27
Configuration(2)	155.03	156.95	22	32
Configuration(1)	203.47	204.39	27	39

Configuration 3 represents improvements in throughput performance of Steps 61-66, of approximately 20% and 37% over Configurations 2 and 1, respectively.

c. <u>Varying Levels of Digital Source</u>

Three levels (0%, 50%, 100%) of digital sources were assumed to be available for a small format compilation using Configuration 3. The purpose of this analysis was to estimate the impact of "digital source availability". Table 4 defines the variables employed, and Table 5 presents the computed values for all steps which are summarized below.

	Man-Hours (m)	Equipment Hours (e)	Total Elapsed Time Work Days	Total Elapsed Time Calendar Days
0% Digital/100% Graphic	389.62	342.56	70	98
50% Digital/50% Graphic	290.43	247.74	58	83
100%/0% Graphic	190.82	152.50	45	63

The primary differences are due to the Data Extraction (Step 40) which ranged from 180 hours to 0 hours.

Variable	% Digital			Rationale
	0%	50%	100%	
Ft	1	1	1	Small format factor.
Jf	1	1	1	Compilation job type factor.
Ng	45	23	0	Full graphic source compilation (1:250,000) requires 45 sources.
Nd	0	10	10	Digital source files available.
Np	1	10	20	Assumed 1 plot for reference frame and 1 plot per digital source file.
Ag	.5	.5	.5	Assumed that 50% of available graphic source are selected.
O	1.5	1.5	1.5	50% overage of info. for base compilation.
Vp	6000	6000	6000	Medium density 1:250,000 scale product.
Ds	.0	.5	1.0	% of source which is already in digital form.
Bj	6	6	6	No. of batch jobs required.
Cs	15	15	15	Minimum number of sessions required for interactive compilation.
Fi	6	6	6	One file generated from each batch job.
LD	20	20	20	Assumed 1 original/16 interim/3 final large screen displays.
RD	60	60	60	Minimum refresh displays to be generated.
Fg	20	20	20	Allowed for 1 generalization action per 20 features.
Mf	.5	.5	.5	50% of all digital features will require manipulation.
Af	.3	.3	.3	30% of features representing compiled base, will require names assignment.
Fo	4	4	4	Number of files generated for final review and production usage.
PR	5	5	5	1 composite and 4 proof plots allowed for.
PL	1	1	1	Flag for on-line proof plotting.
PD	10	10	10	No. of large screen displays for proofing.
RV	30	30	30	Light table review of plots.
HP	6	6	6	No. of hardcopy review plots to support compilation.
Sc	2.0	2.0	2.0	Assumed overage graphic sources are 2X scale of comp. scale.

Table 4 - Assigned Variables - Varying Amounts of Digital Source/1:250,000 Scale Compilation

JOG 1:250,000 COMPILTAION (Config. 3)

Step	100% Graphic			50% Graphic/50% Digital			0%/100% Digital		
	^{m}(Hr.)	^{e}(Hr.)	^{t}(Days)	^{m}(Hr.)	^{c}(Hr.)	^{t}(Days)	^{m}(Hr.)	^{e}(Hr.)	^{t}(Hr.)
10	10	0	3	10	0	3	10	0	3
20	6	0	4	6	5	4	6	10	4
30	30.04	29.87	6	20.85	20.68	5	11.24	11.07	5
(31)	(.5)	(.33)		(.5)	(.33)		(.5)	(.33)	
(32)	(14.4)	(14.4)		(10.56)	(10.56)		(6.4)	(6.4)	
(33)	(15.14)	(15.14)		(9.79(	(9.79)		(4.34)	(4.34)	
40	180.0	180.0	24	90.0	90.0	13	0	0	0
50	6	2.52	8	6	1.89	8	6	1.26	8
60	123.83	126.42	18	123.83	126.42	18	123.83	126.42	18
(61)	(2.2)	(3.45)		(2.2)	(3.45)		(2.2)	(3.45)	
(62)	(7.73)	(7.73)		(7.73)	(7.73)		(7.73)	(7.73)	
(63)	(22.37)	(22.37)		(22.37)	(22.37)		(22.37)	(22.37)	
(64)	(74.7)	(74.7)		(74.7)	(74.7)		(74.7)	(74.7)	
(65)	(14.94)	(14.94)		(14.94)	(14.94)		(14.94)	(14.94)	
(66)	(1.89)	(3.23)		(1.89)	(3.23)		(1.89)	(3.23)	
70	33.75	3.75	7	33.75	3.75	7	33.75	3.75	7
TOTALS	389.62	342.56	70	290.43	247.74	58	190.82	152.50	45

Table 5-Throughput Results-Varying Amounts of Digital Source

d. Digital Revision of a Small Format Product

Production throughput was projected for a revision type job since a high percentage of assignments are product revisions. The variables employed are presented in Table 6. The basic assumptions were that the small format product was already in digital format and 10% of the product data required revision. The computed throughput potential is presented in Table 7 and summarized below.

	Man-Hours (m)	Equipment Hours (e)	Total Elapsed Time	
			Work Days	Calendar Days
Small Format Revision	66.18	52.16	25	35

Variables	Revision Values	Rationale
Ft	1	Small format factor.
Jf	.5	Factor used for revision type jobs.
Ng	5	10% of those graphic sources used for full compilation (new sources only).
Nd	1	1 digital file of original product.
Np	4	Digital data separated onto 4 plots for overlay or composite viewing.
Ag	1.0	All new source graphic will be used to some extent.
O	.1	10% of product data will be updated.
Vp	6000	Medium density 1:250,000 scale product.
Ds	.9	Assumed 90% of all required digital data is available.
Bj	0	All update/revision will be directly performed at interactive subsystem.
Cs	4	Minimum number of sessions required for interactive revision.
Fi	1	1 batch job.
LD	5	Assumed 1 original/3 interim/1 final.
RD	30	Assumed 6 areas examined at 5 displays per area.
Fg	1	Revision jobs will require individual feature generalization actions.
Mf	.1	10% of features will require manipulation.
Af	.05	5% of features will require names assignment.
Fo	2	Final and review files generated.
PR	3	1 composite and 2 overlay proofing plots.
PL	1	1 on-line plotting flag.
PD	5	1 composite and 4 overlay proofing displays.
RV	10	Light table review time.
HP	1	Interim hardcopy plot.
Sc	2.0	Larger scale source material.

Table 6 - Assigned Variables - 1:250,000 Scale Digital Revision

Step	m (Hr.)	e (Hr.)	t (Days)	m (Hr.)	e (Hr.)	t (Days)	m (Hr.)	e (Hr.)	t (Days)
10	5	0	2						
20	6	.5	5						
30	6.603	6.433	3						
(31)	(.5)	(.33)							
(32)	(1.92)	(1.92)							
(33)	(4.183)	(4.183)							
40	1.2	1.2	2						
50	1	.1	2						
60	35.5663	43.1203	7						
(61)	(.332)	(1.166)							
(62)	(1.2763)	(1.2763)							
(63)	(29.82)	(29.82)							
(64)	(.996)	(.996)							
(65)	(2.49)	(2.49)							
(66)	(.652)	(7.372)							
70	10.81	.81	3						
TOTALS	66.18	52.16	25						

Table 7 - Throughput Results-1:250,000 Scale Digital Revision

e. Large Format Compilation

This exercise projected the throughput potential for compilation of a large format (1:500,000 Scale) chart. Values assigned to the model variables are presented in Table 8 . Major assumptions were that 50% of the source data was digital and the other source information was represented by 40 graphics. The results are presented in Table 9 and are summarized below.

	Man-Hours (m)	Equipment Hours (e)	Total Elapsed Time Work Days	Total Elapsed Time Calendar Days
Large Format Compilation	741.50	667.71	119	169

Variables	Values	Rationale
Ft	2	Factor used for large formats.
Jf	1	Factor used for compilation jobs.
Ng	40	Standard 80 graphic sources/50% graphic.
Nd	20	50% of graphic area is digital and is held on 20 files.
Np	20	Minimum 1 plot per digital file.
Ag	.5	50% of graphic sources were selected for major data extraction.
O	1.5	50% overage of feature data is allowed for.
Vp	17,000	Medium density TPC 1:500,000 scale.
Ds	.5	50% of required data is already in digital format.
Bj	10	Batch jobs required assuming that some jobs will include multiple files.
Cs	42	Min. number of sessions required to perform steps 61-66.
Fi	10	One file generated from each batch job.
LD	80	Assumed 4 original/64 interim/12 final large screen displays.
RD	240	4 times the number allotted for small format.
Fg	20	1 generalization action per 20 features.
Mf	.5	50% of features will require manipulation action.
Af	.2	20% of final features will require names assignment.
Fo	4	No. of files generated representing compiled product.
PR	20	Proof hardcopy plots generated.
PL	1	1 on-line plotting flag.
PD	40	Large screen displays to support proofing.
RV	60	Time allotted for light table review.
HP	24	Intermediate hard-copy plots for compilation review support.
Sc	2.0	Assumed average graphic sources are 2X scale of com. scale.

Table 8 - Assigned Variables - Large Format (1:500,000) Compilation

Step	t_m (Hr.)	t_c (Hr.)	t_t (Days)
10	20	0	5
20	6	10	5
30	37.3	36.8	7
(31)	(.5)	(.33)	
(32)	(19.2)	(19.2)	
(33)	(17.6)	(17.6)	
40	255.	255.	34
50	10	5.36	12
60	338.19	345.54	45
(61)	(5.09)	(8.63)	
(62)	(25.73)	(25.73)	
(63)	(63.37)	(63.37)	
(64)	(211.65)	(211.65)	
(65)	(28.22)	(28.22)	
(66)	(4.13)	(7.94)	
70	75.01	15.01	11
TOTALS	741.50	667.71	119

Table 9-Throughput Results-Large Format (1:500,000) Compilation

2. Current Production Standards vs. Advanced System Projections

This section presents a side-by-side comparison of the throughput timings projected for the advanced system vs. standards for current production processes. In all fairness, the reader should recognize that the advanced system projections represent "potential throughput capacity". The current production standards are assumed to represent an average of actual accomplishments based on historical records.

a. <u>Current Product Standards</u>

The purpose of this section is to present information which portrays the current DMAAC chart product standards. This information was collected and analyzed for the purpose of providing a basis for developing the advanced system model and subsequent comparison of throughput capacities.

The product and job types examined included:

JOG 1:250,000	Compilation and Revision
TPC 1:500,000	Compilation and Revision

The following charts present production facts concerning the above production types. The current production system was further examined for purposes of identifying those production steps affected by the proposed advanced system.

Product:	World Wide JOG-G and JOG-A Comp/Recomp (In-House Comp./Contr. Color Sep.) (Aug. 1974)
Process Steps:	40
Total Days:	542
Total Hours:	Man-Hours 1,932.6* Equipment Hours 136.0**

Chart Characteristics:

Scale	1:250,000
Size	18" x 26" (468 sq. in.)
Density	5748 Lineal Inches (12.3 in./sq. in.)

Source Usage: Approx. 45 pieces of source at 1:25,000 to 1:250,000 scales

* Contractor $ were converted to hours

** Photo Lab. equipment was not included.

Product:	TPC Recomp. (In-House) (Dec. 1974)	
Process Steps:	45	
Total Days:	506	
Total Hours:	Man-Hours	4,491.9
	Equipment Hours	124.75

Chart Characteristics:

Scale	1:500,000
Size	36'' x 52'' (1872 sq. in.)
Density	16,766 Lineal Inches (9 in./sq. in.)

Source Usage: Approx. 80-100 pieces of source (10 - 20 MUMS and 10 - 20 pieces of unique source).

Product:	JOG-G Major Revision (BV) (Nov. 1976)
Process Steps:	26
Total Days:	208
Total Hours:	Man-Hours 931.1 Equipment Hours N/A

b. Comparison of Advanced System vs. Current Standards

This section presents current product compilation processes and standards which are replaced or impacted by the advanced system. Those current production steps which are totally or partially replaced by the advanced system are listed in Tables 10-12. Comparison of the current production standards against projected capabilities are summarized below.

JOG 1:250,000 Compilation

	Man-Hours	Equipment Hours	Calendar Days
Current System Total	765.8	4	198
Impacted by Advanced System	696.3	4	198
Advanced System (50% Digital)			
Advanced Processes	290.43	247.74	83
Remaining Current Processes	69.5	-------	19

TPC 1:500,000 Compilation/Recompilation

	Man-Hours	Equipment Hours	Calendar Days
Current System Total	2,120.0	6.0	232
Impacted by Advanced System	1,988.25	6.0	232
Advanced System (50% Digital)			
Advanced Processes	741.5	667.71	169
Remaining Current Processes	131.75	------	30

JOG 1:250,000 Major Revision

	Man-Hours	Equipment Hours	Calendar Days
Current System			
Total	227.0	---------	50
Impacted by Advanced System	182.0	---------	50
Advanced System			
Advanced Processes	66.18	52.16	35
Remaining Current Processes	45	---------	7

Step	Description	Hours		Cal. Days		Impact of Advanced System		
		Man	Equip.	Start	Stop	% Replaced	Hrs. Remain.	Days Remain.
005	Obtain, Anal. & Eval Source	56.0		1	33	100%	0	0
010	Computations	1.8		12	20	100%	0	0
015	Prepare & Inspect. Data	8.0		12	100	100%	0	0
020	Plotter	5.0	4.0	15	100	100%	0	0
025	P/S Support	32	?	33	60	75%	8	6*
030	Compile	490.0		48	171	100%	0	0
035	Comp. Qual. Rev.	60.0		48	171	100%	0	0
040	P/S Support	37.0	?	48	198+	25%	27.5	2*
045	SAA Rev. and Intensity	48.0		172	188	50%	24	8*
050	Sanitization	4.0		175	194	50%	2.0	1*
055	Tint	8.0		175	180	50%	4.0	1*
060	Finalize and R 4N	16.0		194	198	75%	4.0	1*
	Total (Current)	765.8	4.0	1	198+			
	Total (Impacted)	696.3	4.0	1	198			
	Total (Remaining)						69.5	19*

* Start/Stop days overlap with other steps and therefore are not 100% inclusive.

Table 10 - JOG 1:250,000 Compilation Standards and Impact

Step	Description	Hours		Cal. Days		Impact of Advanced System		
		Man	Equip	Start	Stop	% Replaced	Hrs. Remain.	Days* Remain.
005	Prelim. Research	80.0		1	45	75%	20	5*
010	Projection	23.0	6.0	5	60	100%	0	0
015	Grid	12.0		30	60	100%	0	0
020	Comp. Plan	120.0		30	60	75%	40	5*
025	Comp. Photo Support	128.0	?	30	120	75%	32	10*
030	Comp. Photo Support	29.0	?	30	252	75%	21.75	6*
035	Compile	1,540.0		60	210	100%	0	0
040	Comp. Qual. Rev. & Corr.	140.0		60	210	100%	0	0
045	Sanitization	24.0		210	214	50%	12.0	2*
050	Finalize and R4N	24.0		214	218	75%	6.0	2*
	Total (Current)	2,120.0	6.0	1	232			
	Total (Impacted)	1,988.25	6.0	1	232			
	Total (Remaining)						131.75	30*

*Start/Stop days overlap with other steps and therefore are not 100% inclusive.

Table 11 - TPC 1:500,000 Comp./Recomp. Standards & Impact

Step	Description	Hours		Cal. Days		Impact of Advanced System		
		Man	Equip.	Start	Stop	% Replaced	Hrs. Remain.	Days Remain.
005	Obtain Copy	8.0		1	15	100%	0	0
006	P/S Support	10.0	?	5	7	75%	2	1*
007	Grid Compute	6.0		2	6	100%	0	0
008	Isogonics	3.0		14	38	0%	3	2*
009	SAA Update	160.0	?	15	50	75%	40	4*
010	Prepare Markup (R4N)	40		1	50	100%	0	0
	Total (Current)	227.0	?	1	50			
	Total (Impacted)	182.0	?	1	50			
	Total (Remaining)						45	7*

* Start/Stop days overlap with other steps and therefore are not 100% inclusive.

Table 12 - JOG Major Revision Standards and Impact

D. Results

1. Advanced System Model

The production throughput model developed for this analysis provided sufficient flexibility to compute throughput potential for a variety of production situations. The model can be employed for other job types and processing variables.

2. Alternative Configurations

Employing the model to determine the throughput potential of the three alternative configurations for compilation of a 1:250,000 chart resulted in the following:

Configuration	Man-Hours	Equipment Hours	Work Days	Calendar Days
Refresh CRT (1)	386	343	70	98
Upgraded Refresh CRT (2)	337	296	65	91
Large Screen & Refresh CRT (3)	293	251	58	83

Configuration 3 represents a 10% to 15% improvement over Configuration 2 and 15% to 20% improvement over Configuration 1. The major improvements are realized for the interactive processes (Steps 61-66), where improvements in throughput of 20% to 37% were identified.

The above figures represent a sizable advantage for Configuration 3, although the quantitative results could be viewed as less than overwhelming. In summary, the Large Screen Display Device would cost approximately $85,000 more than a hard copy proof plotter, although the Large Screen Display would provide the following advantages:

- addition of an interactive work station to support review and proof plotting and certain generalization processes;
- provides for dynamic augmentation of features to current displays (i.e., selective build-up/overlaying of displays);
- vehicle to view changes to a compilation graphic as the user is modifying feature selection and positioning;
- plot medium is reusable and hard copy output needs to be generated only for purposes of off-line review; and
- on-line large area displaying will allow for "continuity of compilation processes."

3. Advanced System Throughput Potential

Based on the variables applied to the throughput model, compilation of a 1:250,000 graphic (50% digital available) is projected to require the following resources:

	Man-Hours	Equipment Hours	Calendar Days
Advanced System Processes	293	251	83
Remaining Manual Processes	70	-----	19

These figures compare with current production standards of 765.8 man-hours and 198 calendar days. Other comparisons for large format compilations and revision jobs are presented in above section.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. PRC concludes that the compilation study and design analysis resulted in technical information which can be employed to initiate system development. Additionally, the study reveals the apparent shortcomings of current display technology and suggests areas for research and development.

2. Technical areas which were critical and received major attention during the study were: system requirements, functional/ operational definition, display technology, source assessment function, alternative configurations, and production throughput potential.

3. The design goal of "configuring a system composed of commercially available devices" is achievable, except for the source assessment/data extraction hardware device. This hardware device will require special fabrication of optical/mechanical, image projection, and digitizing components. The development complexity and cost of the source assessment device can dramatically increase unless the design requirements are tightly controlled.

4. The configured system represents a best attempt at employing available technology to perform the full range of compilation functional requirements. The most promising system configuration is concluded to consist of a Graphic Compilation Batch Subsystem and Graphic Compilation and Interactive Subsystem. The Interactive Subsystem is composed of three types of work stations:

- o Source Assessment Work Station
- o Interactive Compilation Work Station
- o Proofing Work Station

The different types of work stations primarily is due to the unique capabilities required from supporting hardware. Placement of functionally related capabilities at each of the stations can allow for effective, concurrent use of each of the work stations. Additionally, the design concept allows for combined use of the interactive compilation station and large screen display.

5. One of the interesting fallouts from the throughput analysis is that initial station balancing can be examined. The developmental system (Configuration 3) would consist of three (3) work station types. Actual loading of each work station for production jobs can indicate the ratio of station types which provides optimal station usage. For example, station usage by production steps for a 1:250,000 scale compilation is summarized as follows:

		Station Type	
Step	Source Assessment	Interactive Compilation	Proofing
Source Assessment (30)	13 hours	-----------	12 hours
Data Extraction (40)	30 hours	60 hours*	--------
Interactive Compilation (60)	--------	84 hours	42 hours
Proofing (70)	--------	-----------	4 hours
TOTALS	43 hours	144 hours	58 hours

This pattern of usage would imply that 2 or 3 Interactive Compilation Stations are required per each Source Assessment and Proofing Station. This ratio could be affected by managements optional use of digitizing systems for part of the bulk data extraction (see above*).

6. The advanced system will provide a number of additional benefits to other cartographic production areas. These benefits are not specifically part of the compilation/revision functions although should be considered when evaluating the effectiveness of employing digital compilation techniques and hardware.

- Negative Engraving - the negative engraving phase of chart production immediately follows the compilation/revision phase. Extensive man-hours and calendar days are required for the current manual engraving processes.

  The advanced compilation system will output digital data files. By employing digital symbolization and plotting techniques, significant savings can be realized in the engraving processes. In fact, consideration should be given to employing symbolization software and the large screen display device to generate hardcopy finished plots. This savings should be considered for further cost justification of the advanced system development.

- Digital Data Bank - cartographic feature data which is digitally compiled should be maintained for subsequent product revision and recompilation. Additionally, the digital data can be used for special products and possible production at other DMA centers.

7. An effective interactive compilation system is believed to be one of the most important and professionally advancing ingredients in an advanced cartographic environment. The advent of digital products, digitizing/plotting equipment, data bases and the like, places even more emphasis on the need for the cartographer to be able to efficiently evaluate new source information and display and selectively manipulate cartographic data.

B. Recommendations

1. PRC/ISC recommends that implementation of the Advanced Revision and Compilation System (ARCS) employing available technology be pursued as soon as possible. Systems to provide high quality displays and interactive capabilities are projected to be a crucial ingredient in an advanced cartographic production environment. The implementation should proceed with hardware selection, development specification, software development, and system integration and demonstration. The source assessment hardware device will require special design and fabrication. While the other hardware is commercially available, significant software and procedural technique developments are required. The detailed design and implementation of ARCS should allow, where feasible, for replacement of display hardware with improved or technically advanced devices.

2. The effort resulted in definition of "optimal" display characteristics required to support cartography. Currently available display devices do not support all desired capabilities although certain evolving technology areas offer possible solutions. One advanced display approach was recently suggested which would employ a liquid crystal for the graphic medium. A small liquid crystal would be thermally excited via laser and optically projected to a larger viewing surface. This approach could potentially provide high resolution, high density, selective write/erase, and multiple color displays. It is recommended that RADC consider R&D efforts to pursue advanced display devices in support of cartographic requirements.

APPENDIX A

Product Description and Schedules

ATC Series 200

JOG - A

JOG - G

JOG - R

TPC

ONC

JN

GNC

ATC Series 200

Scale: 1:200,000

Projection: Lambert Conformal Conic and Polar Stereographic

Size: 22" x 29" (Approximately 18" x 26" graphics)

Density: Not available

Purpose: Series 200 are used primarily in planning, briefing and execution of bombing operations.

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	15	110	75	---	---
Equivalent	24.3	98.4	67.2	2.5	2.5
Maintenance	285	190	225	300	300

Joint Operations Graphic - Air (JOG - A)

Scale: 1:250,000

Projection: Transverse Mercator and Polar Stereographic

Size: 22" x 29" (Approximately 18" x 26" graphics)

Density:		
	Light	3170 Lineal Inches
	Medium	5746 Lineal Inches
	High	9201 Lineal Inches

Purpose: To provide Army, Navy, Air Force with a common large scale graphic. Used for tactical air operations, close air support, interdiction by all aircraft at low and very low altitudes. Used for pre-flight planning and in-flight navigation for short range flights using DR and visual pilotage. Also used for operational planning and intelligence briefing.

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	134	16	48	62	54
Equivalent	29.5	28.0	74.9	92.4	65.8
Maintenance	29	31	26	88	79

Joint Operations Graphic - Ground (JOG - G)

Scale: 1:250,000

Projection: Transverse Mercator and Polar Stereographic

Size: 22" x 29" (Approximately 18" x 26" graphics)

Density: Light 3170 Lineal Inches
Medium 5746 Lineal Inches
High 9201 Lineal Inches

Purpose: The Series 1501 Ground is the topographic map version of a coordinated worldwide series at 1:250,000 scale, required to support international and joint service air/ground tactical operations, preflight and operational planning, training, pilotage or operational functions and intelligence briefings.

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	186	84	40	52	80
Equivalent	119.6	61.7	71.4	82.1	92.8
Maintenance	---	6	---	75	70

Joint Operations Graphic - Radar (JOG - R)

Scale: 1:250,000

Projection: Transverse Mercator and Polar Stereographic

Size: 22" x 29" (Approximately 18" x 26" graphics)

Density: Not Available

Purpose: The Series 1501 Radar is the radar version of the worldwide JOG Series.

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	6	6	6	6	6
Equivalent	8.2	5.6	5.6	5.6	5.6
Maintenance	4	6	6	6	6

Tactical Pilotage Chart (TPC)

Scale: 1:500,000

Projection: Lambert Conformal Conic and Polar Stereographic

Size: 41 5/8" x 57 1/2" (Approximately 36" x 52" graphics)

Density:		
Light	6534	Lineal Inches
Medium	16766	Lineal Inches
Heavy	40590	Lineal Inches

Purpose: This chart is designed to satisfy the needs of detailed pre-flight planning and in-flight aircrew use for low and high speed tactical aircraft performing medium/low altitude visual and radar navigation missions. Other uses for this series include support of tactical airlift, target folder preparation, mission analysis and intelligence and staff planning purposes. In addition, this series is the primary cartographic source material used for filmstrips in support of the Projected Map Display Systems of the Harrier, A7D/E and F/FB-111 weapons systems.

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	30	19	45	40	50
Equivalent	39.0	54.9	48.8	51.7	34.0
Maintenance	44	82	50	60	61

Operational Navigation Charts (ONC)

Scale: 1:1,000,000

Projection: Lambert Conformal Conic and Polar Stereographic

Size: 41 5/8" x 57 1/2" (Approximately 37" x 53" graphics)

Density:	Light	6,206 Lineal Inches
	Medium	13,746 Lineal Inches
	Heavy	52,430 Lineal Inches

Purpose: To satisfy the strategic offensive manned bomber forces and other military low altitude navigation requirements. Primary conventional uses for this series are: Low altitude radar navigation, low altitude visual navigation, conventional D/R navigation and celestial navigation. It is also used for planning and intelligence operations (i.e. provides a base for annotation of intelligence information for incorporation into the SAC Combat Mission Folder).

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	2	2	2	---	---
Equivalent	4.3	1.3	.4	---	---
Maintenance	60	54	50	50	50

Jet Navigation Chart (JNC)

Scale: 1:2,000,000

Projection: Transverse Mercator and Lambert Conformal Conic

Size: 41 5/8" x 57 1/2" (Approximately 37" x 53" graphics)

Density:	Light	8,876 Lineal Inches
	Medium	29,318 Lineal Inches
	Heavy	42,074 Lineal Inches

Purpose: To satisfy USAF/USN enroute navigation requirements of current and future aircraft capable of high speed, high altitude and/or long-range performance. This series is specifically designed to satisfy in-flight navigation techniques including Celestial, Automatic Dead Reckoning, Visual, and Radar Pilotage. Also serves for preflight planning, operational planning, intelligence briefings and as a base for various overprints in support of SIOP. JNC's are an integral part of every U&S Command combat mission folder and are input graphics for the small scale requirements of the Horizontal Situation Display filmstrips used in the F-111 and A-7 aircraft. Serves as a base for the LORAN Navigation and CONSOL/LORAN Navigation Series (LNCs and CJCs).

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	23	16	17	13	---
Equivalent	25.5	18	19.5	5.3	---
Maintenance	16	20	23	25	32

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CARTOGRAPHIC COMPILATION STUDY. VOLUME I. SYSTEM REQUIREMENTS A--ETC(U)
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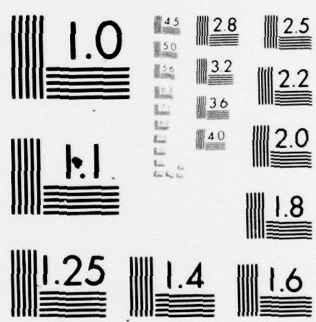

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Global Navigation Charts (GNC)

Scale: 1:5,000,000

Projection: Transverse Mercator and Lambert Conformal Conic

Size: 41 5/8" x 57 1/2" (Approximately 37" x 53" graphics)

Density: Not Available

Purpose: Primarily designed for general planning purposes for operations involving long distances or large areas of interest. It may also be used for in-flight navigation in long range, high altitude, high speed aircraft. It may be used in briefing rooms as a wall chart since sheet lines have been selected considering primary areas of strategic interest.

Production Schedule:

	FY74	FY75	FY76	FY77	FY78
New Production					
Actual	---	---	---	---	---
Equivalent	---	---	---	---	---
Maintenance	9	5	5	5	5

APPENDIX B

Accuracy and Tolerance Requirements

8-4. BASE INFORMATION AND RELATED OVERLAYS.

a.	Delineation of pull-ups from source maps	.010"
b.	Delineation of photos	.010"
c.	Rectified Photography oriented locally	.020"
d.	Fit of reduced film positives of source or pull-ups to projection. In first direction - exact or undersize not to exceed	.005"
	Perpendicular to first direction - exact or undersize not to exceed	.050"
e.	Panel source to control base	.005"
f.	Paneling cut gaps not to exceed	.010"
g.	Plotting of Control Points (Triangulation Stations, PRSL and PIP points	.005"
h.	Positioning of detail to control points	.005"
i.	Mismatch between mosaicked photos - not to exceed	.020"
j.	Vertical reflecting projector transfer (non-critical features)	.020"
k.	Freehand transfer (non-critical features)	.020"
l.	Direct lift of detail from source maps and/or control base to Compilation Manuscript	.010"
m.	Registration of base compilation manuscript, related manuscripts and overlays to the control base	
	Critical overlays or pre-punched materials	±.002"
	Non-critical overlays or non-punched materials	.010"
n.	Lineweights on pull-ups equal to specifications when reduced to scale of the compilation	± .005"
o.	Distortion of features resulting from required compilation generalization - not to exceed	.020"
p.	Displacement of parallel features to allow for clearance of .020"	.005"

All linework on pull-ups, control base, compilation, and related overlays must be opaque and clearly delineated to assure good reproduction quality and prevent possible misinterpretation of features in succeeding phases of production.

Figure 8-4. Base Information Compilation Tolerances

APPENDIX C

DMAAC PRODUCT/SOURCE MATRIX

SOURCES USED BY CDI

CHARACTERISTIC	MAJOR PRODUCT	
	DLMS	RADIOMETRICS
Source	1:24,000 - 1:200,000	1:24,000 - 1:200,000
Projection	Lambert Conformal Polyconic	Lambert Conformal Polyconic
Type of Control	Map Source, DP's	Map Source
Mono-Stereo	95% Mono 5% Stereo	95% Mono 5% Stereo
% Digital	0% Digital 100% Graphic	0% Digital 100% Graphic
Roll - Flat	Flat	Flat

SOURCES USED BY CDI

CHARACTERISTIC	MAJOR PRODUCT			
	S-200	S-250	S-50	Mini-Graphic
Scale	1:50,000- 1:250,000	1:50,000- 1:250,000	----	1:50,000- 1:250,000
Projection	Transverse Mercator	Transverse Mercator	----	Transverse Mercator
Type of Control	Map Source MUM DPM	Map Source MUM DPM	Map Source MUM DPM	Map Source MUM DPM
Mono vs. Stereo	50%-50%	50%-50%	100%-0%	90%-10%
Digital vs. Graphic	0%-100%	0%-100%	0%-100%	0%-100%
Roll-Flat	Flat	Flat	Flat	Flat

Source Factors \ Product	JOG	TPC	ONC	JNC/GNC/LJC and MISC.	Remarks
SCALES	1:25,000 to 1:250,000	1:50,000 to 1:250,000	1:250,000 to 1:500,000	1:5000,000 and 1:1,000,000	Scales shown are normal. Larger scales are used when necessary.
PROJECTION TYPES	* T.M. & P.S. ** T.M. & L.C.C	*L.C.C. & P.S. **T.M. & L.C.C.	*L.C.C. & P.S. **T.M. & L.C.C.	*L.C.C. & P.S. **L.C.C. & P.S.	*Product proj. **Source proj. (normal)
CONTROL	*	*	*	*	*Projection, UTM, Geodetic, Datum transformation data, etc.
MONOSCOPIC PHOTOS	*	*	*	*	*Used whenever available
STEREO PHOTOS	None	None	None	None	
GRAPHIC SOURCE	100%	100%	100%	100%	Litho's, photoprints, micromasters, etc.
DIGITAL SOURCE	*	*		**	*Used for SHADLEN where available. **Used for weather charts and space shuttle charts

Source Factors / Product	JOG	TPC	ONC	JNC/GNC/LJC and MISC.	Remarks
ROLL PHOTOS	*None	*None	*None	None	*Roll photos used for viewing only, skylab photos used rarely for viewing only
FLAT PHOTOS	*	*	*	*	*Rectified/ scaled or chunked as required

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RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C^3) activities, and in the C^3 areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

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